IN-11-CR
293771
115P.

A LUNAR SPACE STATION

Submitted by

UNIVERSITY OF VIRGINIA
NASA/USRA Advanced Design Program
Summer Conference 1989

Written by

LU TRINH
MARK MERROW
RUSS COONS
GABRIELLE IEZZI
HOWARD M. PALARZ
MARC H. NGUYEN
MIKE SPITZER
SAM CUBBAGE

A LUNAR SPACE STATION

Submitted by

UNIVERSITY OF VIRGINIA
NASA/USRA Advanced Design Program
Summer Conference 1989

Written by

LU TRINH
MARK MERROW
RUSS COONS
GABRIELLE IEZZI
HOWARD M. PALARZ
MARC H. NGUYEN
MIKE SPITZER
SAM CUBBAGE

PREFATORY
TABLE OF CONTENTS

LUNAR SPACE STATION

GROUP ASSIGNMENTS

Lu Trinh	Group Leader Mission Planning
Mark Merrow	Graphics CAD/CAE
Russ Coons	Structural Analysis Power Systems
Gabrielle Iezzi	Industrial Processes
Howard M. Palarz	Life Support Environmental Control
Marc H. Nguyen	Shielding
Mike Spitzer	Long Term Effects
Sam Cubbage	Communications Orbital Mechanics

PROJECT OVERVIEW

As part of the ambitious space exploration program that has been proposed for the end of this century and into the next, the return of humans to the moon is one of the primary objectives. In order to accomplish the goal of a permanent moon base, a large support structure must be developed to provide the lunar residents all the materials and equipment that they will need to properly use the moons abundant natural resources. Our Aerospace Vehicle Design team feels that one of the essential elements of this support structure is an orbiting Lunar Station similar to the earth station Freedom. With the above considerations, we are proud to propose a space station concept for the low lunar orbit.

The Lunar Space Station (LSS) is a complete support facility that will have the ability to provide the surface base with fuel, water and equipment ferried from earth. An added purpose of the station will to experiment with manufacturing using lunar materials. Taking advantage of the zero-gravity environment, this facility will produce a superior grade of GaAs crystals for the construction of semiconductive devices. The abundance of silicon oxide and other silicates also allows for the mass production of fiberglass at a high profit margin. Additionally, vegetation of various kinds will be grown on-board. They will have an active role in the air and food cycles of the life support system. These along with other minor experiments will attempt to demonstrate the commercial applications of space exploration.

The obvious design problems, in this case, are the power requirements, space hazards, profitability of the industrial processes and the prolonged zero-g effects. Our project will attack these problems with design concepts and solutions that are feasible with today's technologies. The single obstacle in realizing this project would be the high cost today's space transportation systems.

MISSION SCENARIO

SUBPHASE 1: Initial start-up of Lunar Space Station. First habitation module, cryogenic storage facility, and one lander will be put into lunar orbit.

Duration: 9 months - 1 years.

Starting Year: 2000 A.D.

SUBPHASE 2: Second habitation module along with the Communication and Control Module will be transported to LLO. Permanent manned operation will also be started.

Duration: 1 year

Starting Year: 2001 A.D.

SUBPHASE 3: Medical/Health Module and miscellaneous truss components will be transported and assembled in LLO.

Duration: 6-9 months.

Starting Year: 2002 A.D.

SUBPHASE 4: Agrcultural Module, furnace, and remaining supporting structures will be assembled in LLO in this stage.

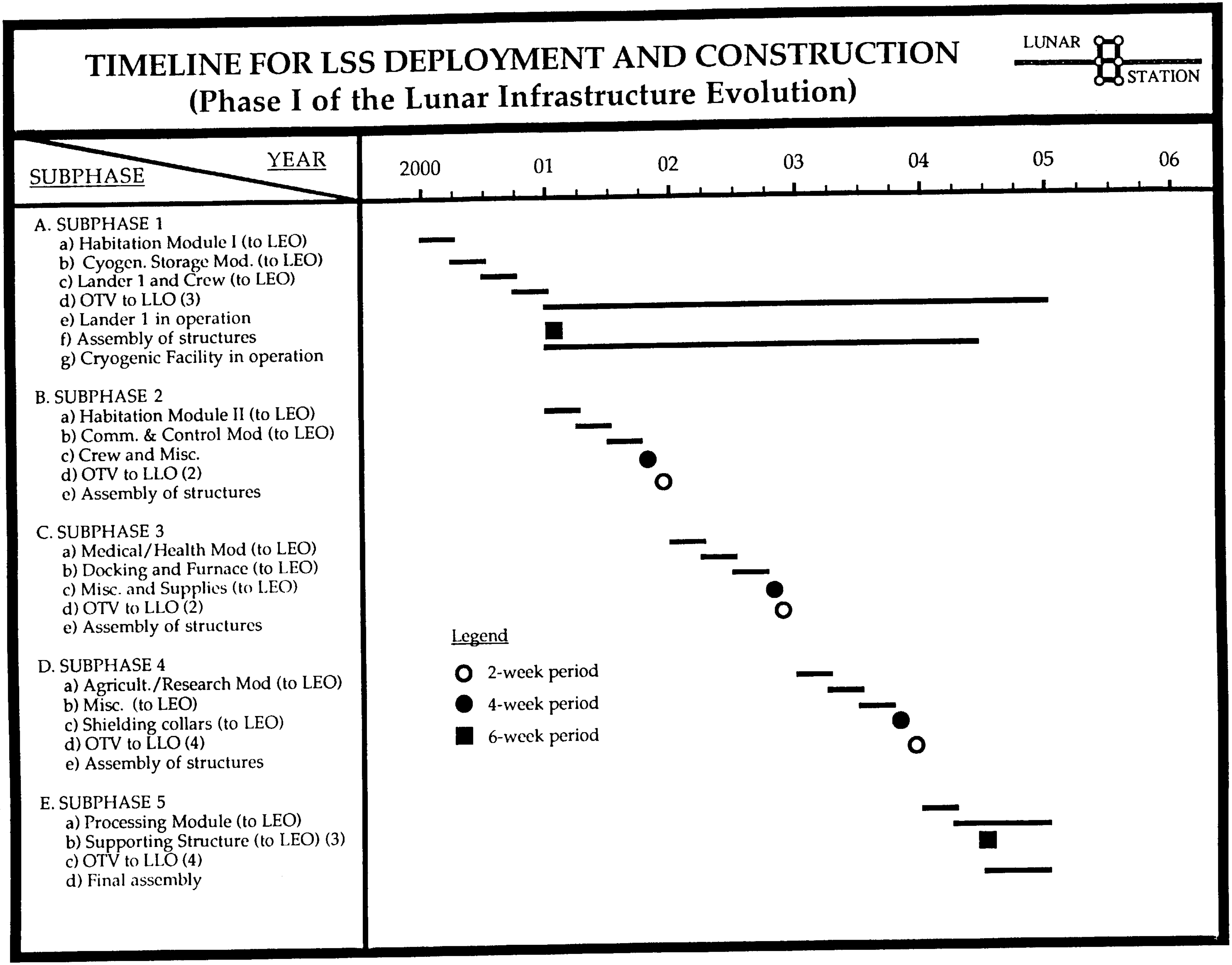
Duration: 9 months.

Starting Year: 2003 A.D.

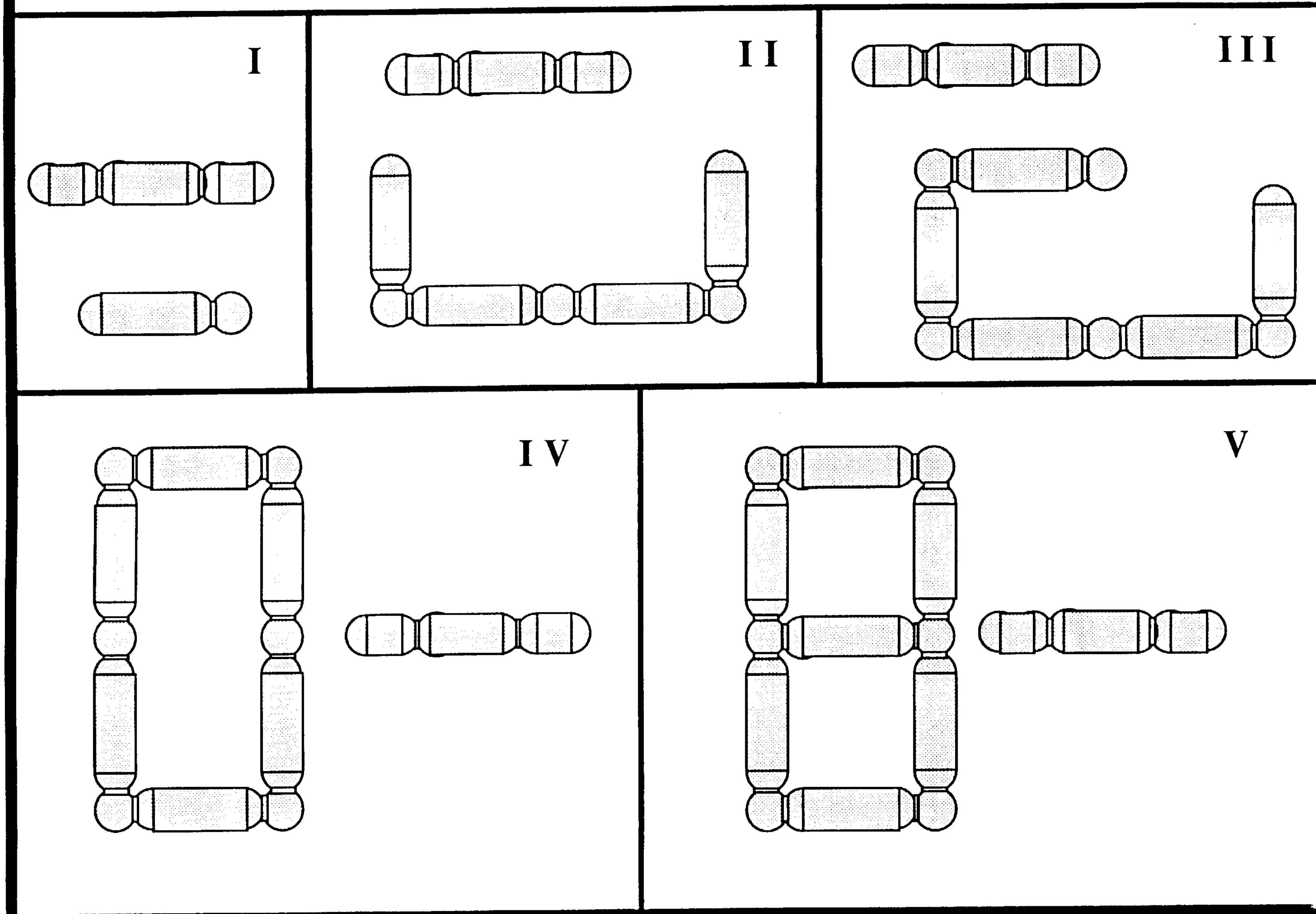
SUBPHASE 5: Completion of LSS. Processing Module arrives in LLO. Complete manufacturing operation will start in early 2005.

Duration: 9 months - 1 year.

Starting Year: 2004 A.D.


TIMELINE FOR LSS DEPLOYMENT AND CONSTRUCTION
(Phase I of the Lunar Infrastructure Evolution)
LUNAR
STATION
SUBPHASE
YEAR
2000
01
02
03
04
05
06
A. SUBPHASE 1
a) Habitation Module I (to LEO)
b) Cyogen. Storage Mod. (to LEO)
c) Lander 1 and Crew (to LEO)
d) OTV to LLO (3)
e) Lander 1 in operation
f) Assembly of structures
g) Cryogenic Facility in operation
B. SUBPHASE 2
a) Habitation Module II (to LEO)
b) Comm. & Control Mod (to LEO)
c) Crew and Misc.
d) OTV to LLO (2)
e) Assembly of structures
C. SUBPHASE 3
a) Medical/Health Mod (to LEO)
b) Docking and Furnace (to LEO)
c) Misc. and Supplies (to LEO)
d) OTV to LLO (2)
e) Assembly of structures
D. SUBPHASE 4
a) Agricult./Research Mod (to LEO)
b) Misc. (to LEO)
c) Shielding collars (to LEO)
d) OTV to LLO (4)
e) Assembly of structures
E. SUBPHASE 5
a) Processing Module (to LEO)
b) Supporting Structure (to LEO) (3)
c) OTV to LLO (4)
d) Final assembly
Legend
2-week period
4-week period
6-week period

SPACE STATION DEPLOYMENT SEQUENCE



DESIGN REQUIREMENTS

A set of system requirements will now be established for a standard mission scenario. This will entail a trip from the ground to Low Earth Orbit via a STS such as the Space Shuttle. Using a fleet of 3 to 4 Orbital Transfer Vehicles (an assumed technology), semi-fabricated components of the Lunar Space Station will be transported to a Low Lunar Orbit. At this point, the remaining construction tasks will be completed in conjunction with the startup of the Lunar Lander Program.

Structural Requirements

I. There shall be a total of 8 modules (by the completion of station build-up in the year 2005): 1 smelting furnace, 1 processing module, 1 research and agricultural module, 2 habitation modules, 1 internal storage module, 1 control and communication module, and 1 medical/health module. Also attached to the truss superstructure will be two liquid hydrogen tanks, one liquid oxygen tank, and a docking facility.

II. Each module must physically fit within the Space Shuttle cargo bay.

III. Hatch configuration for docking and module connection must be compatible with NASA standards for docking hatches - this includes outside and inside dimensions as well as the geometries of the mating surfaces and the access ways.

IV. There shall be sufficient structural shielding on all modules to protect the station from meteorites of up to 1 cm in diameter and travelling as fast as 75 km/sec.

V. There shall be sufficient shielding in safe-haven areas of the habitation modules such that crew members can remain safely (exposure of less than 5 rem) in these modules during periods of intense solar flares (up to 500 rad/day).

Power Systems

I. Power requirement will be rated at a peak of 250 kW with the following distribution :

   A. Industrial processing : 100 kW

   B. Life support : 10 kW/module

   C. Communication and electronics : 20 kW

   D. Miscellaneous : 10 kW

   Note : With the current station geometry of eight modules, the total power requirement is 210 kW with 40 kW allowed for future expansion.

II. There shall be a sufficient number of thermal radiators or heat-sinking devices such that the thermal radiation of power generation will not affect the station as well as any spacecraft in rendezvous with our LSS.

III. Back-up power will come in the form of rechargeable fuel cells. Rated power for the back-up system shall also be set at 250 kW.

Material Processing

I. There shall be a smelting facility which will be shared by the fiberglass production and the processing of GaAs crystals.

II. The formation and processing of semiconductive crystals shall be done in zero-g and zero-pressure environment.

III. Both processes shall depend only on lunar raw materials.

IV. Both processes shall be sufficiently automated such that only remote monitoring will be necessary.

V. Operating capacity shall be set at 9 metric tons per year. This operating requirement shall be met by three separate re-supply missions for the Lunar Lander, each of 3 metric tons.

Orbital Considerations

I. The LSS shall be placed in a low lunar orbit of approximately 200 km in altitude.

II. At this time, the orbit inclination shall be set in agreement with the mission profile of the Lunar Lander which is at 28°.

Life Support

I. Each module shall have its own basic life support system. This will eliminate multiple module failures.

II. Operating cycles for the air, water, and solid waste loops are as follow:

 A. Air cycle will be closed-loop and regenerative.

 B. Water cycle shall be semi-closed with 50% regeneration.

 C. Solid waste cycle will be open loop. Its by-products will be used as fertilizers and plant nutrients.

III. Designed capacity for each ecological system shall be for a maximum of 12 crew members.

IV. The overall re-supply cycle shall be 90 days.

TECHNOLOGICAL NEEDS AND DEVELOPMENTS

As an initial concept study, we will propose many innovative and original engineering designs. They are based on the latest and most current technologies in many fields from agriculture to waste management. Needless to say, advances in these areas will insure the success of our design from an economic standpoint. The following analysis will identify some of our technological needs.

Manned-Space Platform Technologies

I. Launch vehicle:

  A. Improved STS payload capabilities.

  B. Shuttle-derivative vehicle development.

II. Structural materials:

  A. Research to quantify full structural and chemical characteristics of metal matrix, resin matrix, and polymer matrix composites.

  B. Development of radiation-resistant polymer.

  C. Decrease the risk of radiation and material contamination by using metal composite instead of organic composites.

III. Power systems and distribution:

  A. Develop high-strength, high-temperature, lightweight materials to improve nuclear reactor performance for space missions.

  B. Develop highly stable electrolytes.

  C. Application of fuel cells as secondary power source to LEO or LLO missions.

  D. Develop automated power distribution systems.

  E. Examine potential environmental problems associated with high-voltage power systems in LEO or LLO.

IV. Navigation and control:

   A. Development of automated navigation systems.

   B. Improve designs of magnetic bearings for use in gyros.

   C. Examine the application of viscoelastic materials as vibration dampers and suppressor.

   D. Develop detailed computer models for the simulation of sensors and actuators.

   E. Develop more accurate computer models of space structures with natural frequency determination and transient response analysis capabilities.

V. On-board processing and communication:

   A. Development of advanced integrated circuits.

   B. Development of Very-Large Integrated Circuits (VLSI), beyond the current state-of-the-art which is a few hundred-thousands transistors per chip.

   C. Development in fiber-optic systems specifically for space applications (long distant, low power requirements).

   D. Improvement in image and signal processing algorithms such as data compression, feature extraction, pattern recognition, and querying operations.

VI. Environmental interactions:

   A. Improve the predictability of severe radiation storms (solar flares, etc.)

   B. Analyze spacecraft charging by electron and neutron embedding.

   C. Improvements in radiation hardening for electronics.

MMU and RMU Technologies

I. Structures:

   A. Development and integration of teleoperators and Shuttle-attached manipulators.

B. Continue research in robotic and Artificial Intelligence technologies.

II. Power systems.

A. Expand application of Ni/H_2 as a power source.

B. Examine hydraulic power systems for robotic applications in zero-g.

III. Tracking and control:

A. Develop improved arms and manipulators tracking systems.

B. Improve reliablity of robotic control softwares.

C. Decrease hardware response time to be more reactive to softwares.

D. Improve the man-machine interface to simplify operation sequences and hardware complexities.

Lunar Base Technologies

I. Health: Investigate the major physiological problems encountered by man in spaceflight.

II. Human factors:

A. Optimize the allocation of tasks to human and automation.

B. Improve crew station or habitation design.

C. Examine the effects of living quarter size, geometry, and color scheme.

D. Develop more EVA tools and construction aids.

E. Develop and simulate space construction techniques.

CHAPTER CONTENTS

CHAPTER 1

Structural Design

MAIN MODULES

The structure of this space station must provide shelter from the environment of space. The design of any shelter may consist of one large enclosure, several smaller enclosures, or a combination of both. For example, factories often have wide open interiors to permit movement of machinery and workers while protecting them from the surroundings (e.g. rain, low temperatures, etc.). A modular structure is most advantageous in the space environment because it has the following characteristics: relative ease of assembly, flexibility, and safety. With the modular design, most construction takes place on Earth, and then the whole station is lifted into orbit in large sections. Minimized extraterrestrial construction is desirable to astronauts because spacesuits are pressurized, and therefore, a hindrance to movement. Working in a spacesuit for long periods of time is tiring. Also, any extravehicular activity is dangerous because of the harsh environment of space.

A modular station is more flexible because the configuration can be changed, more sections can be added, and others can be removed. All docking hatches are homogeneous so that any two can be joined together.

Finally, a modular facility offers added safety because emergencies can be isolated. For example, if a meteor punctures a module, the pressurized internal atmosphere will begin to flow out. This problem will not harm the other modules if the adjacent hatches are sealed, thus preventing the escape of allhthe atmosphere. The damaged module is then repaired or replaced.

The module design requirements as listed in Ref. 10 are as follows:

a. The module should be made of materials that will provide a service life of 10 years or more without intermediate refurbishment.
b. Module gross weight and overall dimensions will not violate shuttle payload bay constraints.
c. Provide strength and life integrity to sustain a manned shirtsleeve environment of 14.7 psia.
d. Provide adequate internal attachment structure for module function configuration.
e. Provide meteoroid/debris protection at a 95 percent probability of not having a penetration for 10 years.
f. Provide docking/berthing capability to other modules and to the Space Shuttle.
g. Provide dual ingress and egress capability.
h. Provide windows for observation.
i. Impose structural ultimate factors of safety for structural design and analysis.
l. Have factor of safety of 2.0 for pressure loading.
m. Have factor of safety of 1.5 for mechanical and thermal loading.

The facility will have seven cylindrical modules with circular crosssection and a hemisphere dome on each end. The modules are joined by spherical nodes and arranged in a figure eight pattern (Figure 1A). At each joint there will be two hatches with 54 inches of clear opening and an outside diameter of 80 inches. As noted previously, all the hatch dimensions are standardized to allow docking between any two hatches, including that of the Space Shuttle. The size and weight of the modules have been limited by the dimensions of the shuttle. The cargo bay measures 15.0 feet by 43.7 feet, and so each module has a diameter of 14.5 feet and a length of 35.0 feet. Each will be constructed of 2219T851 aluminum (Ref. 10) and weigh about 45000 pounds on Earth, which is under the 65000 pound payload limit of the shuttle. Aluminum was selected for Freedom and this design because it has the following characteristics.

- This material has good strength, a high fracture toughness, a good resistance to stress corrosion, good weldability, and good machineability (Ref. 10, p. 539).
- The nodes will also be constructed of aluminum and have a diameter of 14.5 feet. The only assembly required in space is to join the modules and nodes together. As mentioned before, this simple method is desirable because complex construction in space is difficult and dangerous for the astronaut.

Small windows (1 foot diagonal) will be located in several places on the station. Some of the nodes will contain a window assembly in the hatch opening (Figure 6). The windows will have double pane glass. The outer layer will serve as a shield for the inner layer. The region between the panes will be vented to space to prevent condensation from remaining on the panes. These vents can be closed in cases of emergency.

TRUSS

A truss will provide the foundation and give strength to the station during the various construction phases. Payloads will be stored on the truss and utility lines will run along it. Each truss wing holds five solar dynamic units and rotates at the pivot point to face the sun. The SDU's are also rotated on the secondary shafts that are perpendicular to the main shafts. Asjmentioned before, fine pointing occurs at each SD interface structure. The truss is anchored to the center module and stretches 203.0 feet in both directions. The solar collectors give the station a total length of 536.0 feet. See Figure 1B for the station configuration.

There are two kinds of truss: deployable and erectable. A deployable truss is launched into space fully assembled or in large sections. It is simply unfolded once it is positioned on the construction site. A design mentioned in Ref. 10, page 532, allows a 216foot section of truss with 9f oot members (2inch diameter) fold to an 8foot length. For that reason, this type is appealing however, it is often less compact during transport than an erectable truss. A singlefold deployable truss folds only in one direction, and so the length of its members is limited. Consider a circular crosssection (15 feet dia.) of the Shuttle cargo bay. The truss, which has a square cross section, must fit inside the circular

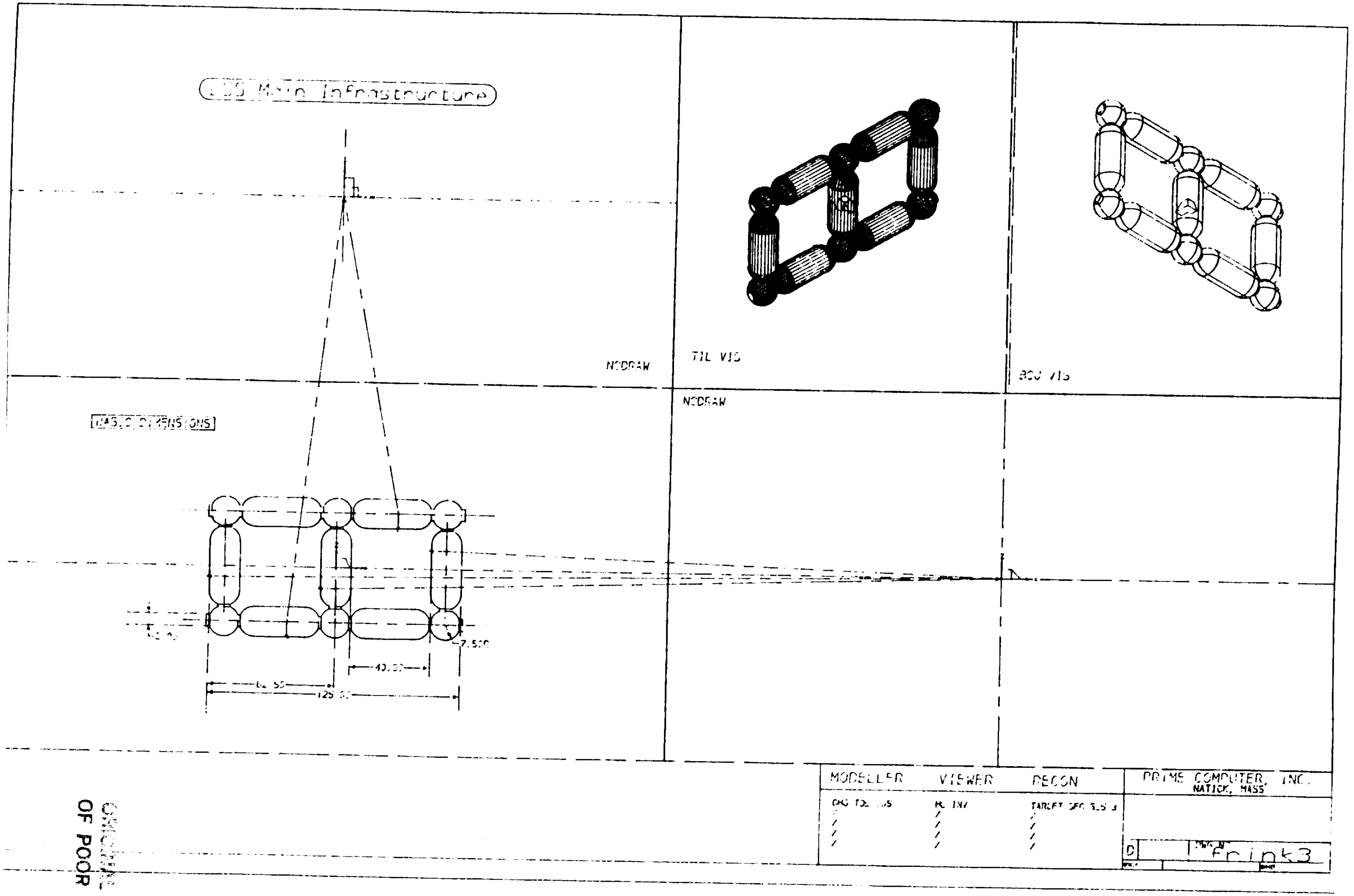


FIGURE 1A

ORIGINAL PAGE IS OF POOR QUALITY

COMPLETE STUCTURAL MODEL

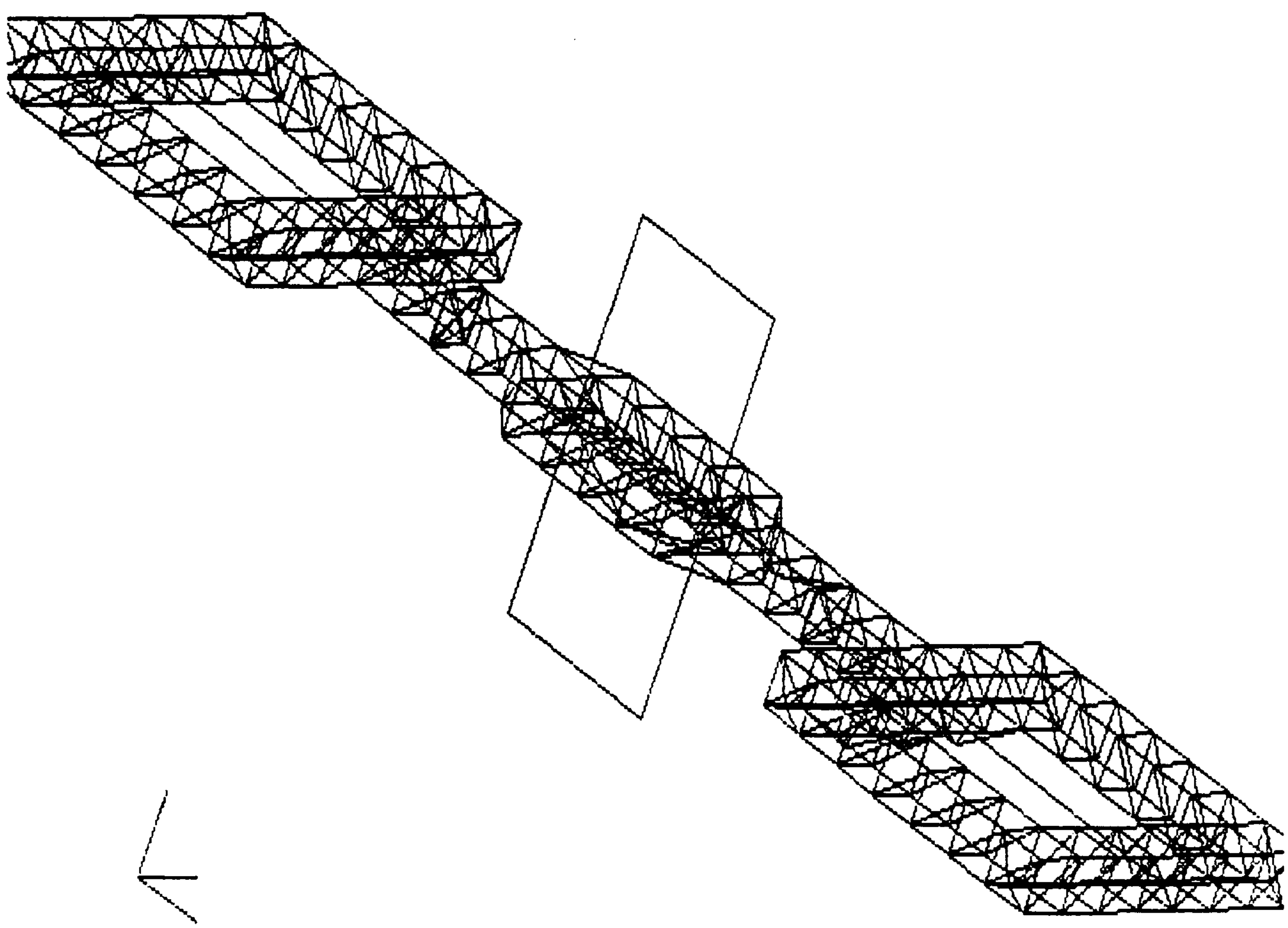


FIGURE 1B

section. This limits the member length to 9 to 10 feet. The erectable truss members are not under this constraint because they are completely disassembled during transport. They have a higher packing density and more packing flexibility; not all have to be in the same area of the bay. In other words, they can be loaded in several bunches wherever there is room. Thus, fewer Shuttle flights are required to lift the same assembled length of truss.

While developing the Space Station Freedom, a comparison was done between a deployable truss with 9foot members and an erectable truss with 15 foot members. The results showed that the erectable truss requires half the parts and half the weight, while providing three times the stiffness (Ref. 10). The obvious disadvantage of the erectable truss is that it must be assembled in space; a tiring, finger intensive task.

The design of this report will use an erectable truss with 14.5 foot members connected at nodes in a redundant arrangement. This gives some margin of safety and allows repairs to be made without disrupting the entire structure. The final configuration will use 957.0 feet of truss. Some assembly will be executed by astronauts, but the bulk of the work will be done by a "spider" attached to a manipulator arm. This device, which resembles a spider, grasps truss members and nodes and connects them as directed by its human controller.

CHAPTER 2

Lunar Space Station Power System

DESIGN SELECTION AND CRITERIA

1.1 Design selection

Power is of major concern to spacecraft and space station designers. The life support, communications, and guidance systems need power to operate. A failure of these systems would likely lead to the death of the astronauts and the loss of the structure. Listed below are the four power supply systems that were considered for this project. Each is ranked for seven important characteristics, with the total points given at the bottom. The solar dynamic system received the highest score and was therefore chosen as the primary power generator for the manufacturing facility. The group decided that the station would require a total of 250 kilowatts of electrical power to operate. Ten units, rated at 25 kW each, will provide the power.

Characteristic	FC	Nuc	PV	SD
1. Powerful (250 kWe)	0	3	1	3
2. Durable in space	2	3	2	2
3. Safe to environment	2	0	3	3
4. Capable of longterm power	1	3	3	3
5. Capable of highburst power	1	3	1	2
6. Safe if damaged	2	1	3	3
7. Cheap and abundant fuel	2	1	3	3
TOTAL	10	14	16	19

Notes: FC = Fuel Cell/Battery; Nuc = Nuclear
PV = Photovoltaic; SD = Solar Dynamic
0: unacceptable; 1: fair
2: good; 3: excellent

1.2 Power Requirement

Fuel cells and batteries are unacceptable as primary sources because they need recharging, which requires a second power supply. Also, the large amount of cells or batteries needed to generate 250 kilowatts makes this choice undesirable. When the SP100 nuclear system is fully developed, it will be able to supply the necessary power with a compact structure. The photovoltaic system is not a good choice because of the huge arrays needed to collect solar radiation. The solar dynamic system uses solar collectors with a smaller total surface area. Large arrays detract from the maneuverability of the station and can even experience drag from impacting particles. Space does have a low density of particles, but it is not completely empty (especially in low Earth orbit).

1.3 Space Durability

The SP100 is the most durable because of the heavy shielding around its core. The solar collectors of the photovoltaic and solar dynamic systems deteriorate over time because of micrometeor impacts and residue from combustion products of passing spacecraft. Fuel cells and batteries are subject to cracking and leaking.

1.4. Environmental Effects

The nuclear option is unacceptable because of the radioactive wake that it generates. This is especially undesirable in a station that has other spacecraft docking regularly with it. Also, nuclear waste and spent reactors arehdifficult to dispose of without adversely affecting the environment. Another problem with the nuclear system is public acceptance. The population is wary of propelling nuclear reactors through Earth's atmosphere with highly explosive rocket fuel. It also fears that orbiting generators will fall to Earth with a shower of radioactive debris (Ref. 1).

If a fuel cell/battery is damaged, it can leak harmfulJ products (gas, liquid, or solid). The photovoltaic and solar dynamic systems do not have these problems.

1.5 Longterm Power Delivery

Fuel cells and batteries are inadequate as a longterm primary source because they must be recharged.The nuclear, photovoltaic, and solar dynamic systems can supply power for long periods of time (years).

1.6 HighBurst Power

A nuclear power source can best supply highburst power. The fuel cell/battery scored low because it is drained more rapidly when high amounts of power are used. The photovoltaic and solar dynamic systems cannot giveJ extra power unless they are coupled with powerstorage devices. The solar dynamic thermal energy storage (TES) is 90% efficient, which is higher than the batteries (70-80%) or fuel cells (55%, Ref. 7a) that are used by the photovoltaic system.

1.7 Safety

The photovoltaic and solar dynamic systems are not harmful if damaged; thus, they scored the highest. As mentioned before, fuel cells can leak harmful materials if damaged. The serious health problems caused by nuclear radiation make this choice unacceptable if damaged.

1.8 Fuel Cost and Availability

The nuclear system uses plutonium, uranium nitride, or uranium dioxide. These are rare and expensive fuels that must be guarded to prevent theft for use in nuclear weopons. Sunlight, which fuels the photovoltaic and solar dynamic systems, is free of charge and in endless supply. Additionally, solar dynamics have the advantage of higher efficiency. The SD engine has a 20-30% efficiency compared to the 14% efficiency of the silicon solar cells of the photovoltaic system (Ref. 7a).

The material needed for the fuel cell/battery (typically NiH2) falls between these two extremes.

SOLAR DYNAMIC UNIT

The following paragraphs describe the solar dynamic unit that provides electricity for this space station. Note that this is the unit that the Rocketdyne Division of Rockwell International is proposing for use on the Space Station Freedom. Ten of these units are used in the design of this report.

Figure 2A shows an entire unit, which consists of theJ following assemblies: concentrator, receiver, power conversion unit (PCU), heat rejection (radiator), electrical equipment, interface structure, and beta gimbal. Note that the electrical equipment is not pictured, but would rest on the interface structure.

The concentrator assembly is an offset parabolic reflector (Figure 2B) that focuses incoming solar radiation on the receiver, located 25.6 feet from the concentrator (i.e. at the focal point). The reflective surface is made up of 19 hexagonal panels that are mounted on a graphite/epoxy support structure. Each hexagonal panel measures 13.75 feet (pointtopoint) by 11.9 feet (flattoflat) and consists of 24 triangular facets. The panels latch together to form the 2336 square foot surface area of the concentrator (Figure 2C), which is less than five inches thick and has a design life of ten years. Solar sensors are mounted on the concentrator to aid in pointing for maximum sunlight.

The solar radiation then enters the cylindrical receiver (85 inch diameter, 117.5 inch length) through a 17.0 inch diameter aperture where it heats the engine working fluid. The working fluid, a He/Xe mixture, is put through the thermodynamic (closed Brayton) cycle desribed below. The heated fluid is expanded through a singlestage radial inflow turbine (7.66 inch diameter), which drives an alternator and a centrifugal compressor (6.42 inch diameter). The fluid then flows through a gas cooler that extracts remaining heat for disposal through the radiator. Next, the fluid goes through the compressor and then back to begin the cycle again. This turboalternator compressor (TAC) is driven at 32000 RPM's. An important feature of the power conversion unit (PCU) is that the shaft that runs through the turbine, alternator, and compressorhis the only continuously moving part. Usually, a machine with few moving parts is less likely to break down.

Also located in the receiver is the thermal energy storage (TES). This is an 80.5% LiF and 19.5% CaF2 mixture that is stored around the He/Xe tubes. The TES mixture is melted when the solar dynamic unit is receiving sunlight. When sunlight is not available, the mixture is allowed to refreeze by giving up heat to the He/Xe. Thus, heat energy is supplied to the system by the mixture instead of the sun.

Eight aluminum panels make up the folding radiator that measures 70 by 25 feet when deployed. The scissors-type mechanism is similar to the one used to deploy the Skylab Apollo solar arrays (Ref. 13). A fluid (FC75, fluorocarbon) is pumped through the radiator tubing which is flexible at the hinge points. Note that the fluid cools the TAC as well as disposing of excess heat from the

SOLAR DYNAMIC UNIT

LUNAR STATION

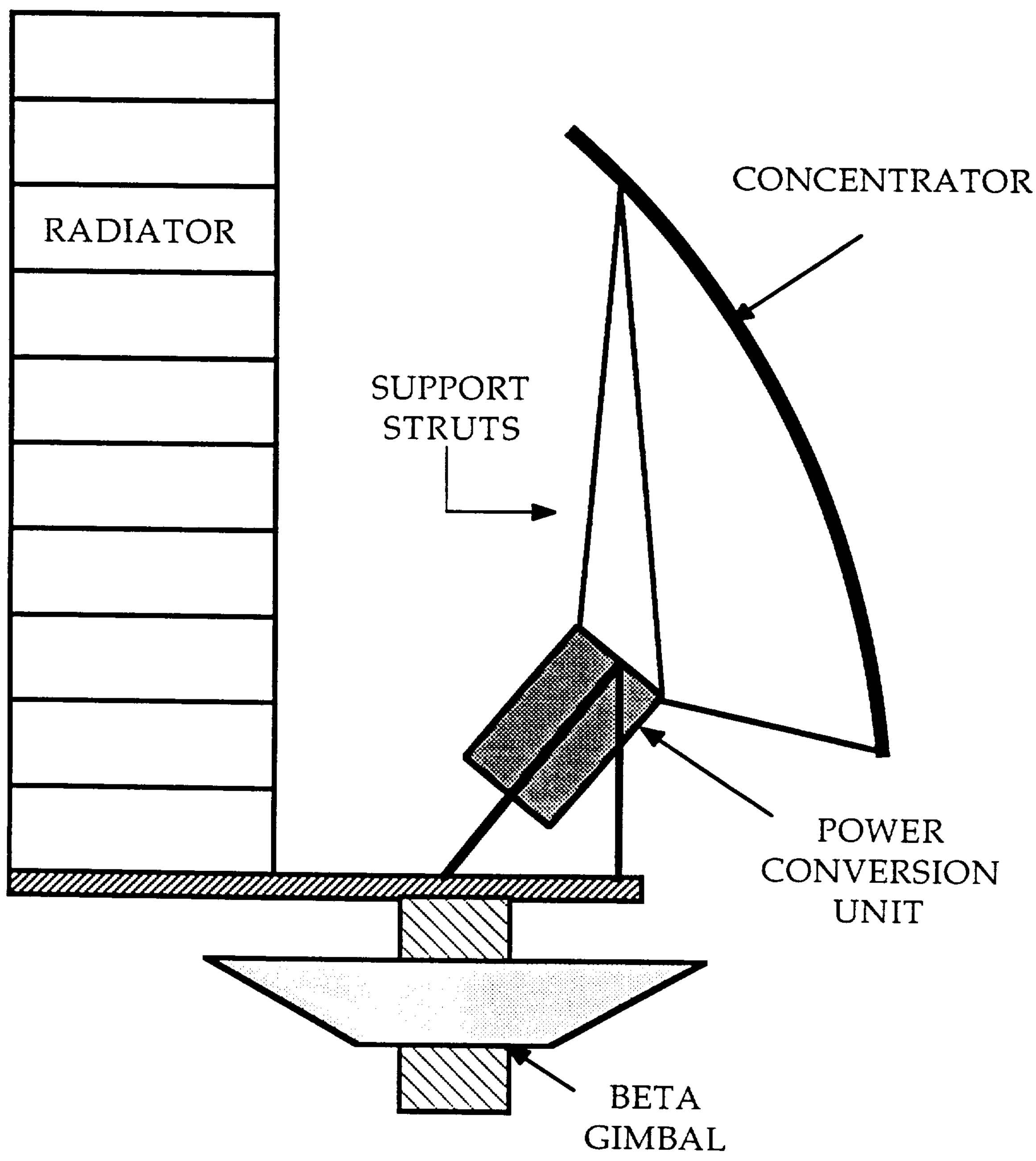
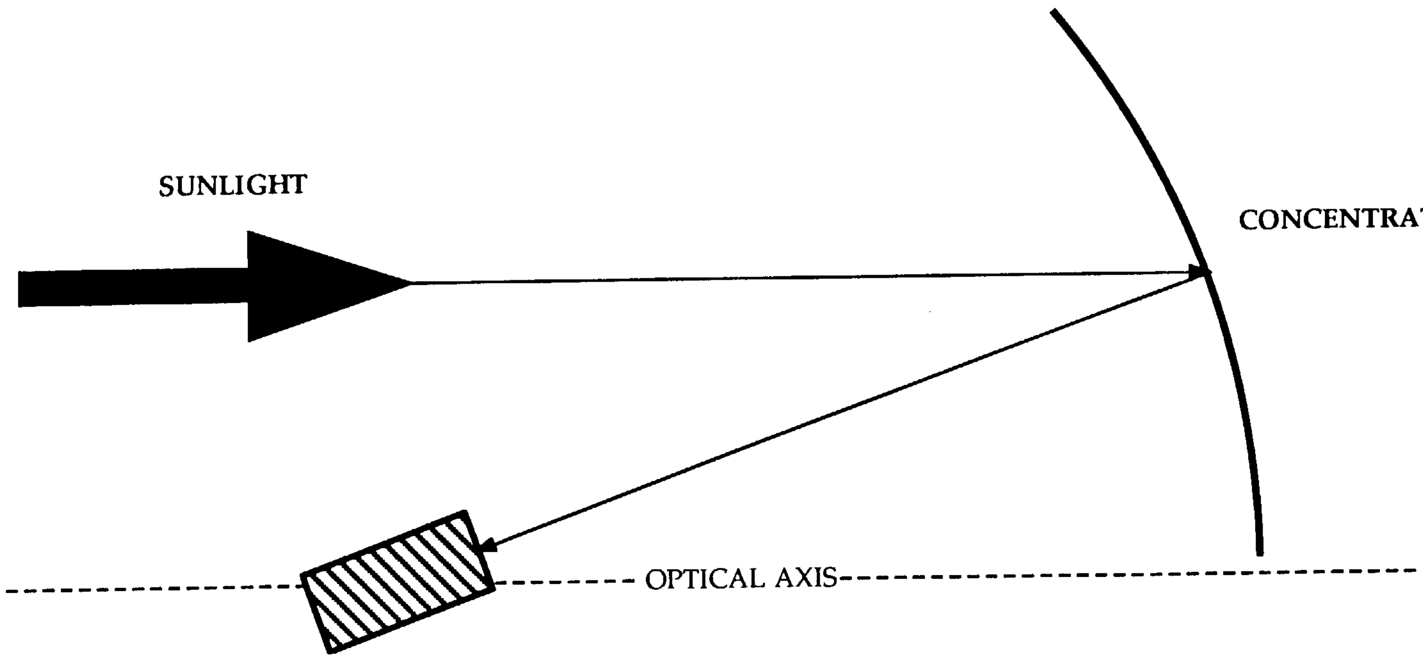


FIGURE 2A

OFFSET PARABOLIC REFLECTOR GEOMETRY

LUNAR STATION

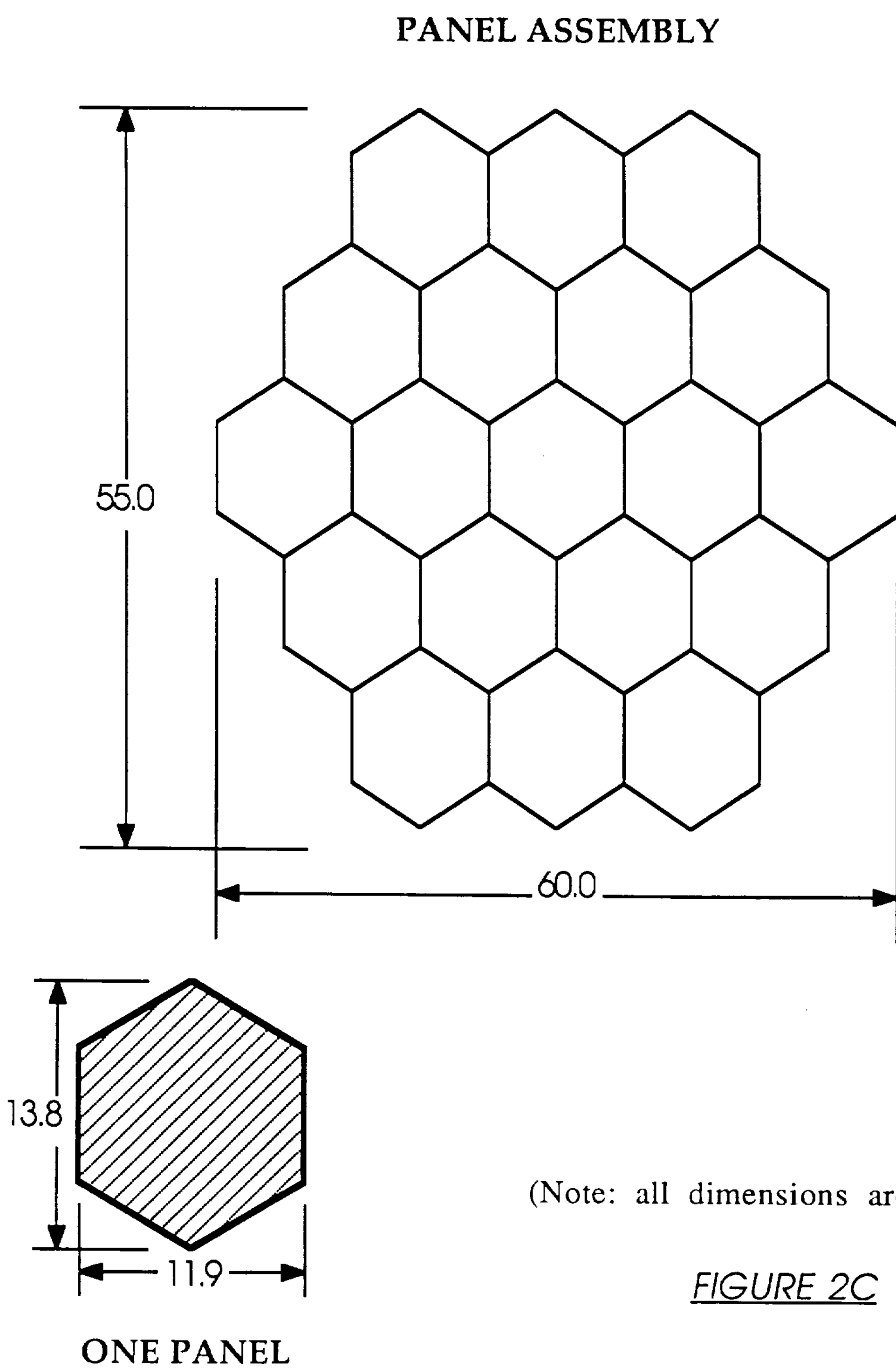


(Figure redrawn from Rocketdyne document)

FIGURE 2B

CONCENTRATOR

LUNAR STATION



(Note: all dimensions are in feet)

FIGURE 2C

LUNAR STATION (INTERFACE DETAILS)

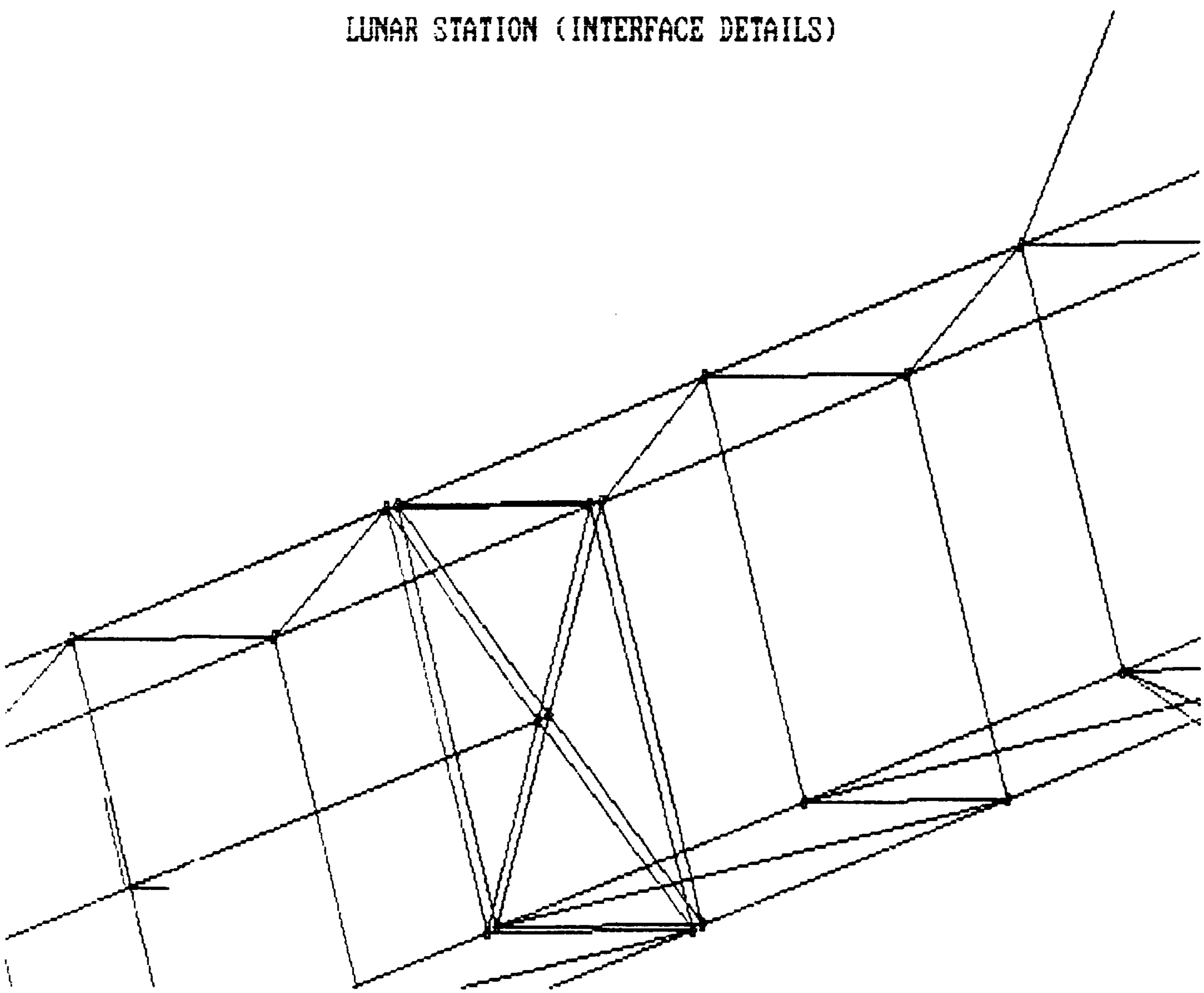


FIGURE 2D

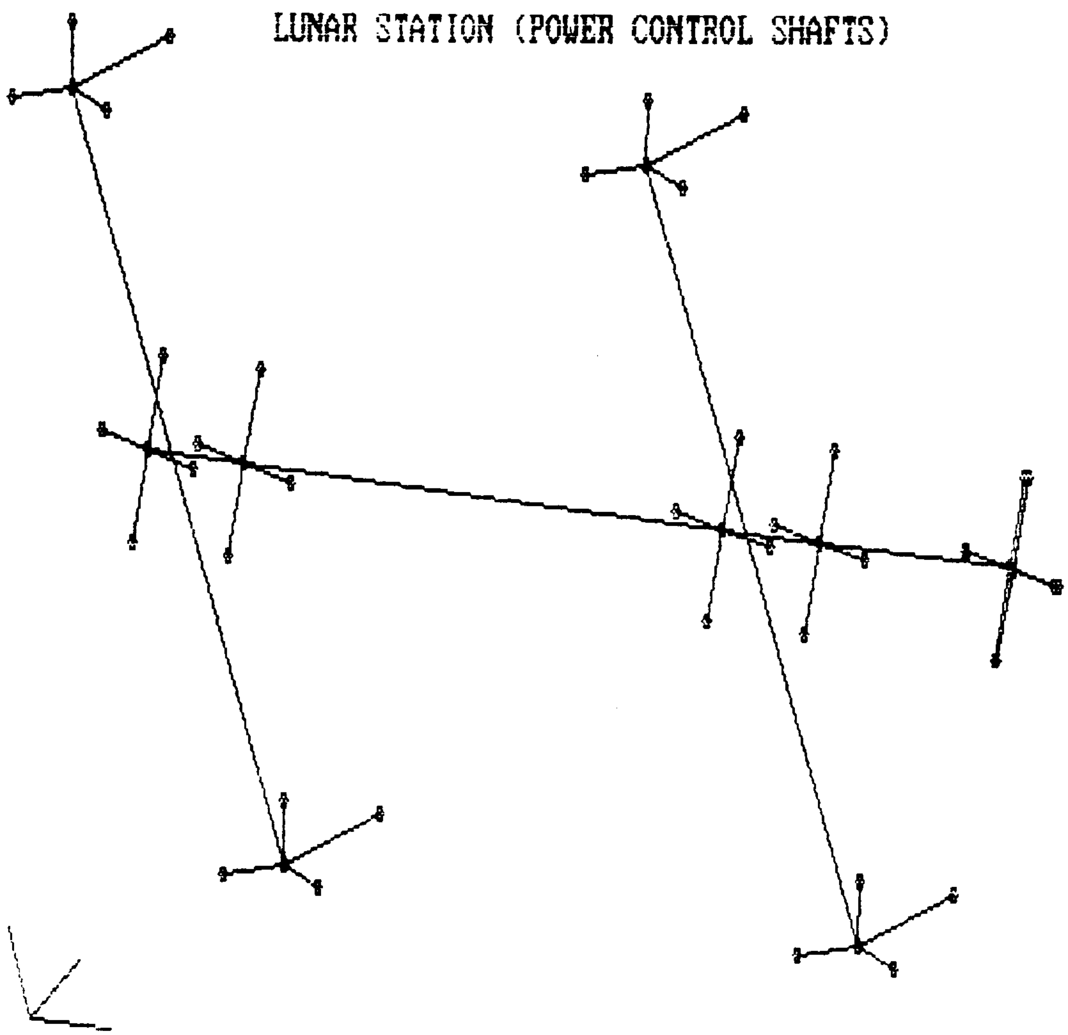


FIGURE 2E-1

LUNAR STATION (POWER CONTROL SHAFTS)

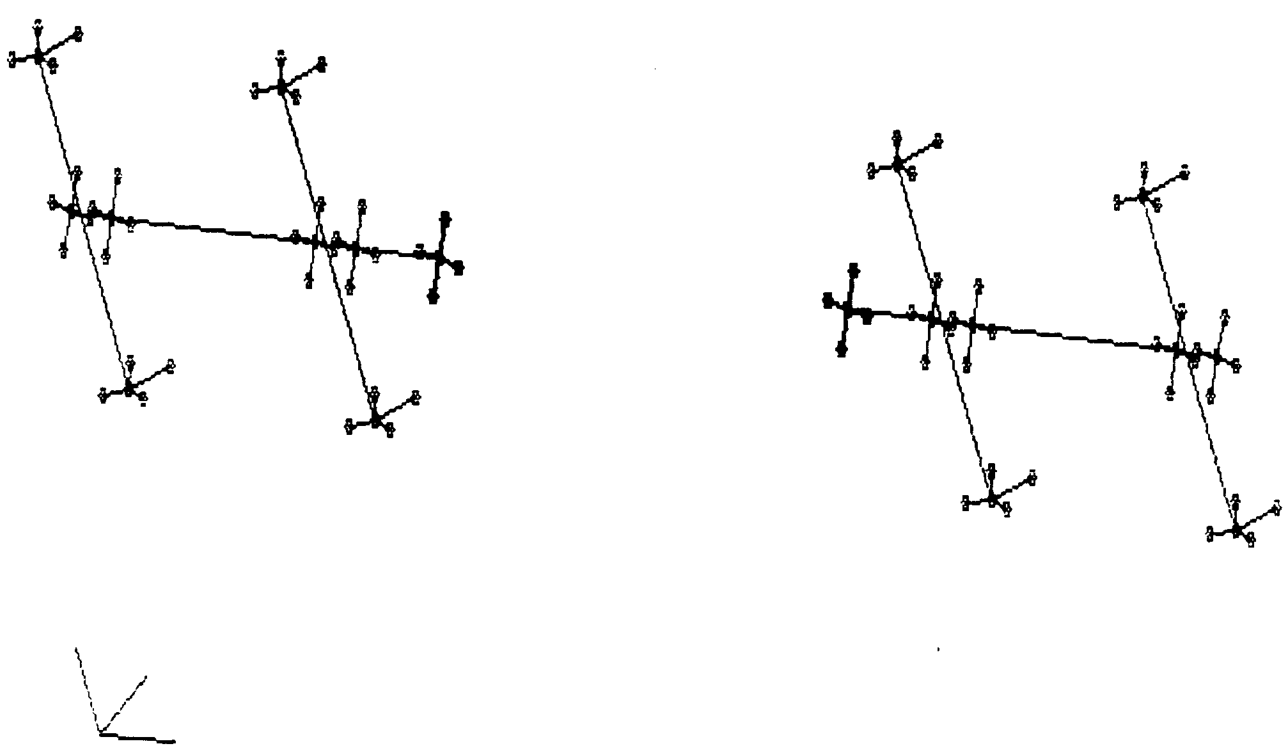


FIGURE 2E-2

working fluid. The electrical equipment receives the current generated by the alternator and sends it to the power management system.

The above components are mounted on the interface structure as shown in Figure 2D and attached to the beta gimbal. Finally, the gimbal is connected to the secondary shaft (Figure 2E) which is used to point the concentrator at the sun. Further pointing is done with the actuators on the interface structure. The component masses and performance data are given below.

COMPONENT MASSES

Equipment	Mass (lbm)	Mass (kg)
Concentrator assembly	3275	1486
Power generation assembly	5604	2542
Heat rejection assembly	3371	1529
Interface structure assembly	828	376
Beta gimbal assembly	606	275
Electrical equipment assembly	564	256
TOTAL	14248	6464

OPERATING PERFORMANCE

Parameters	Min *	Max **
Alternator electric output	32.15 kWe	36.42 kWe
Net cycle efficiency	33.75%	27.6%
Turbine inlet temperature	1361.5 F	1401.6 F
Turbine efficiency	89.60%	90.1%
Compressor efficiency	84.20%	84.7%
Alternator efficiency	93.40%	92.7%
Recuperator effectiveness	0.940	0.926

* Minimum Insolation Sunrise

** Maximum Insolation Sunset

Note: The above charts are taken from the Rocketdyne document (Ref. 13, Table 3.14, Table 3.2.2.22).

POWER STORAGE BACKUP SYSTEM

NiH2 batteries will also be used on the station to store power from the solar dynamic units. This type of battery offers minimum weight (50% lighter than the NiCd battery) and high reliability (Ref. 7a and 11).

CHAPTER 3

Manufacturing and Processing Systems

CHAPTER CONTENTS

INTRODUCTION

1.1 Overview of the Report

The aim of this section is to determine the manufacturing and agricultural processes to be conducted on the lunar space station. The processing is determined based on an established criteria. This criteria acknowledges the important aspects that influence space processing.

Fiberglass production, growing crystals, and space gardening are the selected processes. Each process is investigated along with the advantages and disadvantages of conducting it in space. Solutions are offered on the best way to handle any problems that are encountered with processing in space.

The processing section can have overlapping work with the life support section, but it is basically different from the other design components. The other components' designs are necessary to complete a functioning station. The area dedicated to processing, however, is not required for the survival of the station. The functions of the processing area are to successfully complete industrial work and to aid in the overall space station support. This entails producing materials to be used on the station, or in other places, and to conduct processes that would help the station be self-supportive and more efficient [3].

The beginning part of this section determines the processing to be done by setting the criteria on which to evaluate the decision. Next, previous space experiments are investigated for the range of possibilities in processing. This section concludes with a discussion of the processes chosen.

The final section is the feasibility study. This section includes elaborations on each process and then discusses the advantages and disadvantages of conducting these processes in a lunar environment. Along with that discussion, specifically why the process was chosen and what will be done with the process' finished product is addressed. This section ends by attempting to solve any problems that arise by doing this process in space. The report is completed by summing up all the vital information on processing in space. The information is then interpreted so that the benefits may be obvious. The report finishes with the recommendations on the manufacturing and agricultural operations to be performed on the proposed lunar station.

SELECTION OF THE PROCESSING

2.1 Criteria for Choosing the Processes

In order to determine the "best overall" processes to be accomplished on the station, it must be defined what "best overall" means. This consists of the criteria by which the processes are decided. The three factors are the materials needed for processing, the cost of production and worth of the finished product, and the aid it provides to set up a self- supportive station.

To begin with, the materials used for the operations are a major consideration. Because the station is so far away from the Earth, the cost of transporting equipment, workers, and materials can be extremely expensive. That is why where the raw materials are taken present an issue, making distance an important element. If the materials are close to the station, it provides easier transportation of the materials as well as lowering the cost. Since close proximity is a deciding factor, the moon was the most likely candidate. This also maximizes the utility of the lunar base. If the materials needed can be retrieved straight from the moon, the cost and deliberations of transportation can be drastically reduced.

A second concern is the basic costs of production, materials and equipment. The economics of space processing should be explored because of their complexity. The cost of all the components must be kept as low as possible to ensure a financially worthwhile venture.

In addition to exploring the expense of processing, another aspect of economics should be considered. It was noted that some products can be improved qualitatively by being produced in space. This means a material made in space is enhanced, so theoretically its finished product yields a higher financial value. With the production of some items manufactured in large quantities, it is possible that high financial rewards will be seen with this type of endeavor. This will help the station to economically support itself.

The last factor involved in making the processing decision deals with the station's maintenance. Because of the station's distance from the Earth, it is necessary to set up a station that can function on a day to day basis on its own. This is known as a regenerative life support system. Using this technique the station is able to be self-supportive. It would benefit the system, maintenance, duties, and crew if the station were organized in such a manner that would enable the station to function independently. With this in mind, the processing choices could aid in setting up a regenerative station [3]. The influences of making the processing decisions can be broken into three basic groups. The first is the importance of obtaining the required materials from the moon due to its close location with respect to the station. The second is the cost of production and the worth of the end product. The last influence is helping the station become self-supportive. All three of these influences contribute to the decision made as to which processes are the best overall processes for this lunar station.

2.2 Range of Possibilities

After determining the criteria on which to base the selection, it is necessary to explore the range of possibilities. The range of processes that can be completed in space is quite diversified. It consists of areas such as lifesaving medicines, communications, agriculture, metals, and science. The knowledge of these diverse areas comes from previous space experiments. It also comes from research that has been done on Earth to predict the results that would arise in a microgravity environment [7, p.1].

Research began on space processing with such experiments as growing crystals. Many experiments have been conducted like that in science and deal with all types of materials including metals. These experiments involve the strengthening of metals by having them constructed in space. Other research has been in communications where positive results can already be seen, by the average person watching cable television. Lifesaving medicines have also been explored. The advancement of making medicines can obviously benefit all human kind, so this process has been pursued in space projects. As far as the area of agriculture is concerned, studies have been conducted on Earth and on recent space missions for growing plants in space [7, p.4]. All of these sections of research contribute to the band of knowledge that has been gathered on space processing. These diverse areas prove that there is indeed a beneficial effect on processing in space because of the difference in environments between the Earth and space. After researching the range of possibilities available for the lunar station, it is necessary to determine which ones best match the set criteria.

2.3 Determination

With the criteria in mind, three processes were chosen that suit the intended purpose of the lunar station. Those processes are the production of fiberglass, growing crystals, and a space garden. For the production of fiberglass, the process includes taking soil, smelting it, and removing impurities to have molten glass which is manufactured to make the fiberglass. The crystals are grown to be used for semiconductors and need a place to be grown. Finally, the space garden includes growing different plants for a variety of purposes.

The following material explores the feasibility of these processes. To do this, it is essential to look at the advantages and disadvantages of conducting them in space. Problems will arise in production, so the next step is to provide possible solutions for them.

PRODUCTION OF FIBERGLASS

3.1 Reasons Process was Chosen

This process can benefit by being conducted in space as shown from previously performed experiments. The results show that the fiberglass made in space is more uniform and stronger than if made on Earth. This means that the fiberglass produced in space is of better quality.

The production of fiberglass lends itself well to the described criteria. The best feature is the fact that it can be made solely from lunar soil. Secondly, the process has many interesting applications signifying the possible financial benefits. Thirdly, the fiberglass can add to the station's regeneration. Lastly, an extra plus for the production is that it is relatively self-sufficient. It only requires monitoring the equipment [8, p.14].

Figure 3A shows the materials used in fiberglass production. Also in Figure 3A the materials found in lunar soil are documented from previous investigations. It is evident that from these two tables that fiberglass can be made using only lunar soil. With the lunar base working with the station, the base would be able to supply the station with the needed lunar soil. In the design of the station, a place can be made available that is used to hold the soil. This will enable the process to take place by just extracting the necessary soil from the holding tank [8, p.4].

The resulting fiberglass can be used on the station, the base, or sent back to Earth. The station and the base can be made more self-supportive if they rely on themselves for a construction material.

LUNAR SOIL COMPOSITION

LUNAR STATION

AVERAGE COMPOSITION OF LUNAR SOIL (Wt. %)

OXIDE	APOLLO 11	APOLLO 12	APOLLO 16
SiO_2	42.0	46.4	44.
Al_2O_3	13.9	13.5	26.
CaO/MgO	19.9	20.2	21.
FeO/TiO_2	23.2	18.2	6.

IDEAL FIBERGLASS CRITERIA

SiC_2	60%
A'_2C_3	5%
CaO/MgO	35%
FeO/TiC_2	0%

FIGURE 3A

This in turn would save money because this material would not have to be sent up to the station from Earth. Different applications for which fiberglass can be substituted are indicated by Figure 3B [3].

3.1 General Description of the Process

There are many ways to conduct the process of making fiberglass. Information on the methods like the mineral wool, steam-blown, flame attenuation, spinning, and rotary processes has shown that they would be negatively affected by the microgravity environment. Two others processes have been extensively researched, because they are less affected by the microgravity environment. These types are called the textile and the spinnerette. After exploration of textile and spinnerette methods, the spinnerette was chosen. Although the spinnerette method can have problems with the microgravity, the textile method has too many problems dealing with it and requires too much attention [8, p.8].

The spinnerette method which is planned to manufacture the fiberglass uses basically five major parts. The parts can be seen in Figure 3C. They include:

glass tank	-	The tank holds the molten glass.
fiberization disk	-	The disk is perforated with many small holes along its edge through which the molten glass is forced. This makes the small glass fibers.
motor	-	The motor accelerates the disk so the fibers can be generated.
matrix generator	-	This part applies the matrix, an adhesive substance, to the glass fibers which bounds them together.
collection surface	-	This is a cylindrical shield which collects the fibers after they are released from the disk.

The idea behind this process begins with the molten glass that is contained in the glass tank. The glass is forced down onto the fiberization disk by the force of gravity from which it is expelled through holes around the disk by centrifugal force. The glass fibers are held together by matrix that is applied as the fibers are coming out of the disk. The benefit of doing this process in space is that it aids the use of the centrifugal force and helps the disk to stay free from clogging [8, p.11]. The disk has to be balanced and mounted so that it can be stable through the duration of the process. This is just to make sure that the disk remains balanced and free from clogs. It is estimated that the disk will be accelerated by the motor to 3000 revolutions per minute [8, p.18].

The data that is gathered using lunar soil for fiberglass production is taken from a site investigated by a former moon mission. Using this data, it was determined that mining the moon would be simple, because the raw material was so plentiful. The soil particles were very small so crushing is not necessary. It can be estimated that 5 tons of the soil will be needed to produce 1 ton of fiberglass [8, p.1].

Applications of Silica and Other By-products

RANK	APPLICATION	EARTH BASELINE MATERIAL	EARTH BASE-LINE MATERIAL MASS (T)	RECOMMENDED LUNAR SUBSTITUTE MATERIAL	EQUIVALENT LUNAR MATERIAL MASS (T)	EARTH ALLOY MATERIAL MASS (T)
a	Photovoltaic cell covers	Borosilicate glass	21,658	Fused silica glass	21,658	0
b	Solar cells	Silicon	14,775	Silicon	14,775	<< 1
c	Photovoltaic cell substrate	Fused silica glass	14,439	Fused silica glass	14,439	0
d	Primary solar array structure	Graphite composite	6,208	Foamed silica glass	12,416	0
e	Solenoid/coil windings, etc.	Copper wire	5,980	Aluminum wire	2,865	0
f	MPTS waveguides	Graphite composite	5,257	Foamed silica glass	5,257	0
g	Klystron heat pipes	CRES tubing	3,892	CRES in Klystron, low alloy steel elsewhere	3,542	350
h	Power transmission busses	Aluminum sheet	3,535	Aluminum sheet	3,535	0
i	Klystron/dc-dc conv. radiators	Aluminum sheet	2,749	Aluminum sheet	2,749	0
j	Klystron solenoid cavity	Copper mach. part	1,820	Aluminum part, copper coated	785	90
k	Klystron poles dc-dc transformer	Iron mach. part	1,758	Iron mach. part	1,758	0
l	Klystron collector radiators	Copper sheet	1,539	Aluminum sheet	779	0
m	Klystron housing	CRES mach. part	1,524	Aluminum cast and mach.	515	0
n	Solar cell interconnects	Copper, vacuum deposited	1,456	Aluminum, vacuum deposited	697	0
o	MPTS antenna & other structure	Graphite composite	1,210	Foamed silica glass	2,420	0
			87,800T		[illegible],190T	[illegible]T

FIGURE 3B

SPINERETTE METHOD

LUNAR STATION

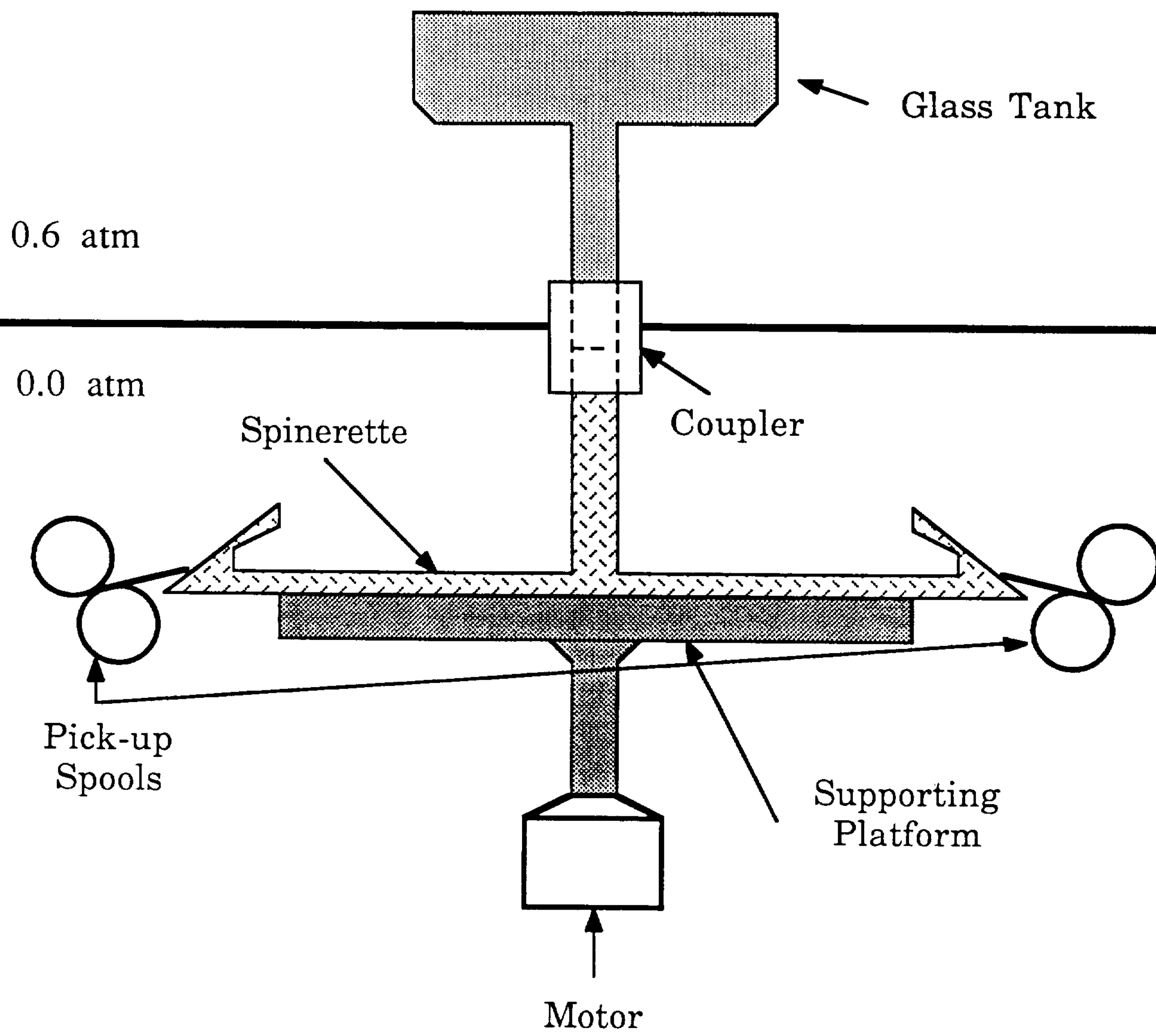


FIGURE 3C

(Lunar Fiberglass: Properties and Process Design, Clemson University, USRA Design Project, 1986)

As mentioned, the soil, which has been transported from the base, can be placed in a holding tank. Then, as needed, the soil can be taken and placed in a smelting furnace on board the station. The smelting furnace is used to melt the soil and remove all of the impurities. The molten silicates, as the melted soil is called, are placed in the glass tank and are ready to begin the spinnerette process.

3.3 Problems Found and the Solutions Suggested

What has been described previously is the outline of how the spinnerette method works in Earth. This method has taken into account gravity and all of its effects. Therefore, adjustments must be made to accommodate this process to the lunar environment. Problems arise in production, because this process was adapted to work in the gravity filled environment. Figure 3D briefly lists the general problems found. As the production starts non-uniform fibers are formed because they drag on the collection surface. This means that the fiberglass formed is not strengthened by the benefit of uniform fibers. A lower quality fiberglass results. Consequently, it has been planned to discard the first batch of the production run so only high quality uniform fiberglass will be manufactured [9].

The disk not only must be kept balanced and free from clogs but it must also must be flawless. It will take two crew members to monitor the production run to make sure that the disk is kept in line. Movement of the processing module during this time could cause unwanted disturbances. The disk could become unbalanced or worse yet it could become unmounted [8, p.13]. This relates to the fact that the transportation device of the lunar base, the lunar lander, will have to dock with the station to unload soil and any other provisions. This necessity of docking could cause motion of the module which would endanger the results of the present production run. To handle this possible problem, it has been determined that docking should not be attempted during a production run. Strict schedules for docking should be kept so that production runs can be scheduled at other times. This would enable the docking and the fiberglass manufacturing to occur without hindering each other because they would be conducted at separate times [3].

Another movement that could interfere with the making of fiberglass is the quick and abrupt acceleration of the thrusters. Thrusters are used to keep the station in the planned orbit. They are only needed for adjusting maneuvers. If the thrusters make quick acceleration changes, this could cause unnecessary motion of the station. To solve this potential problem, it has been planned to have constant thrusters or at least those with only very small changes. This way the thrusters will be able to do their job of keeping the station in its planned position while the possibility of their disrupting the fiberglass production is avoided [10].

The next cause for concern deals with gravity. As it has been explained, the orbiting lunar station will experience a microgravity environment. This goes back to Newton's Law of Gravity which is based on the relative distance an object is away from the Earth. A gravity gradient is the change in gravity, and it is not beneficial to this operation. The gravity should be limited to one tenth of the force of the gravity on Earth. This problem's solution is identical to the one solving the thrusters' one. If the thrusters are kept constant or at least to having only small acceleration adjustments, the gravity gradients do not pose a dilemma [10].

PROBLEMS WITH SPINNERETTE METHOD

1. Drag on collection surface as processing begins
2. Disk monitoring
3. Limiting acceleration
4. Zero pressure
5. New construction

FIGURE 3D

The final concern is a major one. This deals with the pressure felt on the process. To produce fiberglass by the spinnerette method, the lower the pressure is the better. Pressure felt by this process has detrimental effects. It produces bubbles in the molten glass. These air bubbles cause the fibers to break as they are streaming out from the disk. Although the fibers cannot be stopped altogether from breaking, the breaking can be minimized so that the strands can be longer. The longer the strands are the stronger and more uniform the resulting fiberglass will be [9].

In dealing with this concern, the zero pressure in space, as explained before, presents itself as an attractive alternative. This would mean conducting the process out in space by exposing the whole processing module to space by a hatch. It would allow for easy access to the soil which is being held outside the module. It would also keep bubbles out of the molten glass which in turn would help the process run more consistently. The process has been basically redesigned to deal with this problem [10].

The redesign of the system is shown on the right side of Figure 6, while the old one is on the left. This design includes the processing module exposed to space by a hatch. The plan of this system begins with the design of the tank, holding the molten glass, being directly connected to the smelting furnace that has just treated the soil. This way the pure soil can flow right into the glass tank. In order for the flow to take place, there must be a pressure difference between the two areas. Since space has zero pressure, pressure must be kept in the furnace. This enables the glass tank to experience zero pressure, yet the soil can readily flow from the furnace, with a pressure greater than zero, to the zero pressure glass tank. The next step is to get the molten glass from the tank to the fiberization disk. This can be done if the rod, connecting the tank and the disk, and the disk are spinning. This propels the molten glass onto the disk where it is made into fibers and held together with the matrix. The fiberglass can be processed into spools for easy transportation [10].

The problems encountered by producing fiberglass in a lunar orbit by the spinnerette method have been acknowledged and solutions have been offered. The gravity force and the pressure force felt on the process along with disk considerations represent the concerns. Basically, the solutions include keeping the disk monitored and balanced, allowing the thrusters to cause only minimal movement of the station, and discarding the first non-uniform batch of fiberglass. The redesigned process allows it to be compatible with the lunar environment which solves the remaining problems. The new design includes the processing module to be out in space by an opened hatch. This allows the production to take place under zero pressure which ensures more uniform glass fibers. These solutions attempt to make the spinnerette method of fiberglass production feasible in a lunar orbit.

GROWING CRYSTALS

4.1 Reasons Process was Chosen

Growing crystals for semiconductors is the second process chosen, because it fits well with the assigned criteria. The crystals to be grown can be made from the already mined lunar soil since it has the elements needed to grow the crystals. Next, semiconductors are worth a great deal of money.

Another good feature of this process is that there is previous experience growing crystals.

Earlier experiments completed on crystals in space have yielded plenty of results which have shown overwhelmingly that crystals grown there are more uniform and free from defects and irregularities. Because gravity hinders the growth of some types of crystals, growing crystals on Earth is not as effective as growing them in space. Crystal experiments there have indicated the possibility of their being able to be 1000 times larger than those on Earth. Melt growth, float zone growth, solution growth, and vapor growth are basic ways to grow crystals [11, p.xix]. It is intended to capitalize on the research done and the demand for these crystals by producing them in space. Figure 3E ranks the products manufactured with lunar soil in terms of profit. This helps to clarify two points: that semiconductors can be made from lunar soil and the finished product is worth a great deal of money.

Semiconducting devices are becoming more in demand. They are being used for all types of solid state devices: "transistors, diodes, rectifiers, scintillator, particle- counters, gauss meters, thermoelectric generators and coolers, magnetic switches, magnetoresistances, surge protectors, infra-red detectors, and filters [12, p.2]." Semiconductors are also being used in making "phosphorescent and fluorescent screens, solar energy convertors, detectors of visible and infra-red radiation (some fire alarms are of this type), resistors, capacitors, and the theory of the solid-state is playing an increasing part in the development of newer ceramics, glasses and industrial catalysts [12, p.3]."

All of these electronic devices have progressed because of advancements made with semiconductors. The research and development of semiconductors have been able to drastically reduce their size and heighten their abilities. This in turn has had outstanding results on some industries, like the computer industry. A desk top computer of today using new electronic components is able to have the same capability as a room of computing machines years ago. From this it is easy to see the demand for more research and production of semiconductors. Considering that better quality semiconductors can be made in space, even more doors can be opened for the expanding technology.

4.2 General Description of the Process

Silicon is used as an example, because this semimetal is used in the largest amount of industrial applications. An Earth way of producing silicon begins with a silicon oxygen compound which has to be reduced with carbon to produce plain silicon along with the by-product of carbon dioxide. The resulting silicon must be made purer before it can be ready to be processed. Two more reactions are carried out before the silicon is subjected to a process which purifies it even more. This process, zone refining method, can be used over and over again to produce silicon until it produces the intended purity which can be refined up to 99.9999% pure [13, p.510].

To generate a semiconductor crystal from a semimetal like silicon, it must be bombarded by an addition of selected impurity atoms [13, p.513]. "Because impurity atoms have a major effect on the electrical properties of a semiconductor, it is necessary to use extremely pure silicon and to add precise amounts of impurities of carefully controlled composition to the crystal in order to obtain the desired electrical property [13, p.514]. The background of semiconductors is absolutely necessary to grasp the

FIGURE 3E : Industrial Applications of Space

Sequence Number	Description	$/Kg	Total Shipped Value 10^{+6} $ of SIC	Total Mass 10^{9} kg	Sector Energy Consumption 10^{9} kw-hr
1	Complete Guided Missiles	11.0	3,348	0.305	NA
2	Industrial Patterns	6.76	161	0.024	NA
3	Optical & Radio & TV & Sighting Equipment	6.17	7,848	1.271	NA
4	Semiconductors	6.03	2,182	0.362	3.3
5	Telephone and Telegraph Apparatus	5.68	3,674	0.647	5.2
6	Porcelain Electrical Supplies	5.55	223	0.040	2.0
7	Calculating, Accounting, Office Machines - NEC	5.29	1,007	0.190	1.9
8	Aircraft Engines & Engine Parts	5.15	3,538	0.687	6.5 (1)
9	Electronic Computing Parts	5.11	5,186	1.015	4.1
10	Vitreous China Food Utensils	4.83	67	0.014	NA
11	Aluminum Rolling and Drawing	4.29	3,338	0.778	25.9
12	Engineering & Scientific Instruments	4.09	846	0.207	2.0
13	Mechanical Measuring Devices	4.02	1,448	0.360	NA
14	Watches & Watch Cases & Clocks	3.89	761	0.196	0.9
15	Industrial Controls	3.85	1,115	0.289	1.7
16	Ophthalmic Goods	3.84	461	0.120	0.9
17	Automatic Temperature Controls	3.82	591	0.155	1.0
18	Small Arms	3.81	320	0.084	NA
19	Non-clay Refractories	3.76	278	0.075	4.8
20	Jewelers Finding & Materials & Lapidary	3.60	264	0.073	NA
21	X-Ray Apparatus & Tubes	3.56	120	0.034	0.3
22	Abrasive Products	3.51	721	0.205	3.9
23	Radio & TV Receiving Sets	3.51	3,605	1.029	2.1
24	Fine Earthenware Food Utensils	3.46	60	0.017	NA
25	Electronic Components - NEC	3.44	3,808	1.106	7.9
26	Primary Non-ferrous Materials - NEC	3.19	325	0.102	6.7
27*	Machine Tools - Metal Cutting Types	3.16	1,152	0.365	3.1
28	Surgical Appliances & Supplies	3.07	1,182	0.385	1.5
29	Hand Saws & Saw Blades	2.98	158	0.053	NA
30	Electron Tubes	2.76	1,142	0.413	2.9
31	Special Dies & Tools & Accessories	2.59	2,985	1.150	7.4
32	Cutlery	2.57	347	0.135	0.9
33	Costume Jewelry	2.57	383	0.149	0.6
34	Pumps & Compressors	2.38	2,254	0.946	4.0 (1)
35	Aluminum Castings	2.27	1,031	0.454	7.4
36	Measuring & Dispensing Pumps	2.10	189	0.090	0.3
37	Non-ferrous Rolling & Drawing - NEC	2.08	1,011	0.486	4.2
38	Hand & Edge Tools - NEC	2.07	1,001	0.483	2.9
39	Other Ordinance & Accessories	1.99	388	0.195	NA
40	Surgical & Medical Instruments	1.95	781	0.400	1.0
41	Ball & Roller Bearings	1.95	1,243	0.636	4.6
42	Engine Electrical Equipment	1.91	1,652	0.864	3.0
43	Ammunition (No Small) - NEC	1.87	1,206	0.644	NA

integral part that they play in modern technology. Although these semiconducting materials begin on the periodic table of elements, semiconductors have been researched and developed to a point of having a resounding impact on the world of electronics. Further development will serve to even greater enhance the effort of expanding and improving solid state devices.

4.3 Problems Found and the Solutions Suggested

The desired result of growing semiconductor crystals is to produce them with a "high and controlled degree of chemical and crystalline perfection [11, p.125]." Various methods have been explored to do this such the Bridgman, Czochralski, and zone melting processes. These methods have been established for working on Earth. Between the Bridgman and the zone melting process, the zone melting process seems to be favored to be performed in space as concluded from previous space experiments. This process benefits from the space environment for reasons such that the melt is not readily contaminated, and the crystal size is not limited like it is in gravity. The melt is the liquid phase from which the crystal is to grow. One drawback of this process is that it needs to be monitored by highly trained crew members and complex computer systems [14].

The decided method is the Czochralski method, because it is a compromise between the Bridgman and the zone melting processes. This type of processing is similar to the zone melting in that the growth is not restricted, and it does not contact the crucible walls. The crucible is the structure that contains the melt. Czochralski method is like the Bridgman method, because they both use a hot crucible [14, p.438].

"The crystal is withdrawn with the speed v from the melt during the growth process [14, p.439]." The process involves the melted substance forming a crystal as it evolves through the neck. Temperature and pressure are controlled during this whole process.

Because this process relies on gravity for some basic functions, it must be adapted to be performed in microgravity. First of all, temperature changes are experienced so convection takes place which interferes with heat and mass transfer. Also hydrostatic pressure plays a part in the process too. A suggested adaptation of the Czochralski method is used in this implementation A crucible is not needed to contain the process here, but a movable piston is placed around the melt which is shaped into a cylinder. This is arranged so the pressure of the melt can be regulated. Another addition to this adjusted process is the idea of a mask placed at the bottle-neck of this cylinder. The melt generally molds to form a sphere, but some forces need to be applied to the level of the melt. These forces are produced through the mask. The mask is then able to equalize the force resulting from the formation of the crystal from the melt. This will keep the liquid at the mask level as it should be. During this process, the liquid melt can grow into a crystal at an adjusted rate [14, p.440].

After exploring the impact of improved semiconductor technology, it is quite simple to understand the push for growing crystals in space where they can be made more pure and free from defects and irregularities. The semiconductor also has many applications; so there is a definite market for them. Besides the financial worth of semiconductors, it is helpful to the station that they can be made from lunar soil. Since growing crystals was decided as a fitting process, a method was adjusted to enable them to grow satisfactorily on the station. The Czochralski method was chosen with some minor changes to turn the melt into crystals.

SPACE GARDEN

5.1 Reasons the Process was Chosen

The agricultural process of a space garden was chosen as the third process to be done on the lunar station because of its benefits. The advantages of doing this fit the established criteria. However, the advantages are not just economical, and it does not even use lunar soil. The main link to the criteria has to do with helping to set up the space station with a regenerative life support system. In other words, setting up a space garden will help that station be self-supportive in areas of food, oxygen, and waste. This enables the station to function more on its own instead of relying on supplies from Earth. Since the station is planned to exist indefinitely, its self- sufficiency becomes a major concern. Not only will this arrangement be beneficial in the case of emergency barring transportation of supplies, it has economical and psychological effects. Economically speaking, transportation costs will be lowered along with saving money by reusing products on the station. Psychologically and nutritionally, the crew will benefit by eating fresh foods to which they are accustomed [3]. The regenerative idea can be seen in Figure 3F. Lighting, nutrients, and atmosphere control are delivered to the plants. Then, in return, the plants serve as food and nutrients to the humans, as well as, helping their atmosphere control. Humans and plants have perfectly compatible air needs. Humans breathe in oxygen and breathe out carbon dioxide while plants do the exact opposite. This enables their atmosphere control systems to complement each other. The lighting and nutrients are given to the plants by the crew. Then the plants will produce food for the humans' consumption.

5.2 General Description of the Process

The space garden is an innovative process that has not actually been employed. Research has been done on the process though because of its impacts. The process of space gardening is a complex endeavor, yet it has obvious value to the well being and health of the crew. Also as mentioned, it is used to help set up the station with a regenerative life support system. An in-depth study has been conducted on a space garden called CENTAUR. All substances used in connection with this process have to be agreeable to the environment set. The humidity, temperature, and pressure all must be regulated so that the plants can receive a controlled environment for productivity purposes. As far as the CENTAUR structure is concerned, the components should be simple to construct, easy to reach in case of problems, and quick to repair. Since area on a station is at a premium, the system must consider its volume and mass [15, p.12].

With all of the specifications in mind, the CENTAUR design is a cylindrical structure which houses the plants in rows that are adjustable to accommodate the growing plants. This basic design can be seen in Figure 3G. The lighting, temperature, and pressure are regulated throughout the cylindrical chamber. The nutrients and water are administered through feed tubes running the

A CELSS SCHEMATIC DIAGRAM

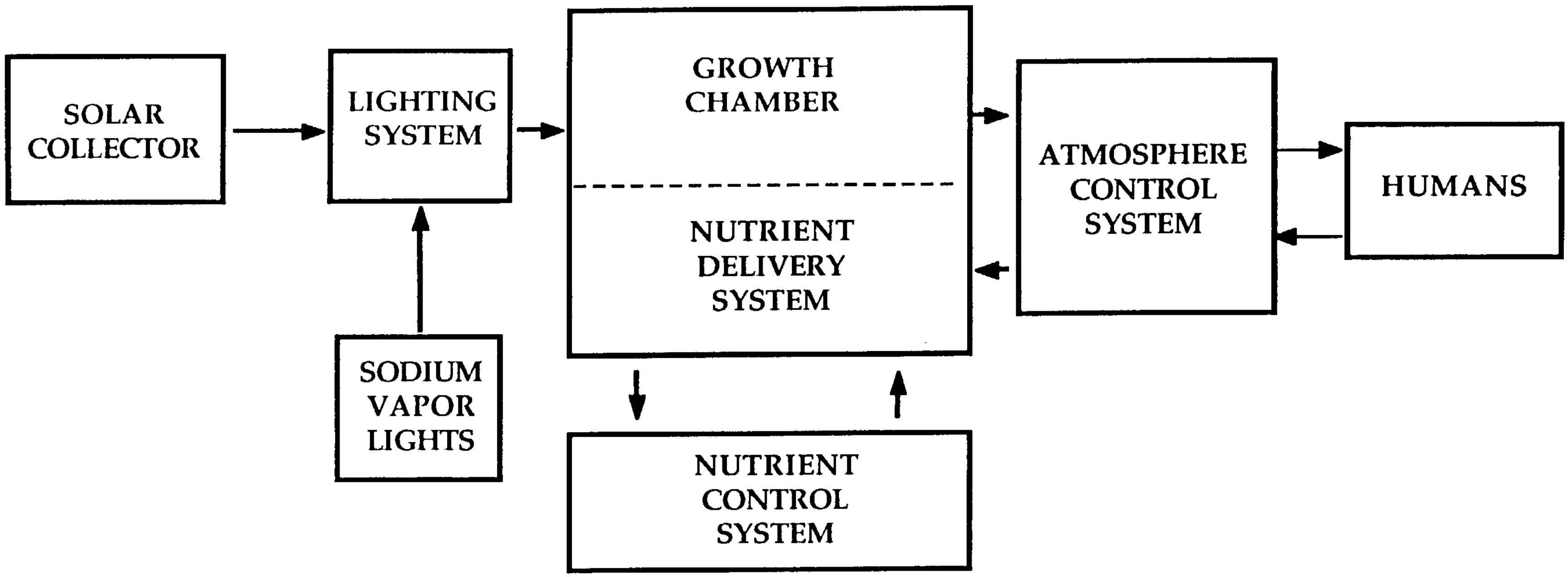


FIGURE 3F

(Regenerative System For Growing Higher Plants in Space, University of Florida, USRA Design Project, 1986) distance of the canopy. The length of the canopy is determined by the area of the plants and the size of the chamber. This formula is shown in Appendix B [15, p.6]. The lighting, temperature, pressure, nutrients, and water supply are all monitored and regulated by a computer.

The potential plants are wheat, bush beans, green beans, irish potatoes, sweet potatoes, rice, soybeans, cowpeas, and lettuce. These were chosen on their nutritional value and their growth habits. The intention of CENTAUR is to be able to supply 99% of the nutritional needs of eight crew members in a time span of six months from implementation [15, p.3].

5.3 Problems Found and the Solutions Suggested

Although this concept has been deeply researched, there will most likely be inevitable concerns with it. Because of this, it has been determined that it would be unwise to declare the intention of supplying 99% of the crew's nutritional needs. Therefore, considering the constant demand for food on the lunar station, the space garden should plan to furnish only part of the crew's food or at least until the garden is able to support the entire food requirements. The garden could concentrate on high yield foods allowing it to evolve into its role as the main food supplier. Yet at the same time, it will provide the atmosphere control and some fresh food. The lunar station will still be moving towards being regenerative [3].

In terms of the computer regulated temperature, pressure, lighting, nutrients, and water, the desired amounts of these parameters will be calculated before hand. Although after implementation, they may need adjusting. Planning should allow for the possibility.

A major concern of this system is the potential for biological pathogens, disease causing agents, and contaminants entering this closed loop environment. Because 90% of the nutrients are consumed by the plants, only a small amount will be recycled. Then of this recycled portion, over 90% of it will flow through the plants' pores and be released as pure water vapor. With this scenario, it has been concluded that the possibility of the little amount of recycled nutrients carrying contaminants is quite small. To take care of any biological pathogens, it is suggested to also cycle through chemicals that are nonpoisonous to humans and plants but will eliminate any pathogens [15, p.21].

Perhaps the largest drawback of this process has to do with the ability of these plants to regenerate. So far research claims that plants in space are unable to reproduce. This means after a plant has had its season of production it will die and not be able to germinate another generation. Perhaps research could continue with the implemented space garden but it still remains a possibility that even with that microgravity research, plants will not be able to be assisted in regeneration. At that time, it will be necessary to conduct an analysis to weigh the benefits of a space garden with the plants seeds sent up to the station when required to begin the garden again [10]. It is basically determined that the best ways to solve the potential problems of the space garden are with careful planning and trial and error. Trial and error becomes necessary for this process since it has never before been implemented. Through the beginning plant growth, the optimal plant conditions will become obvious. Also the capabilities of the garden for supplying the nutritional needs to the crew will be

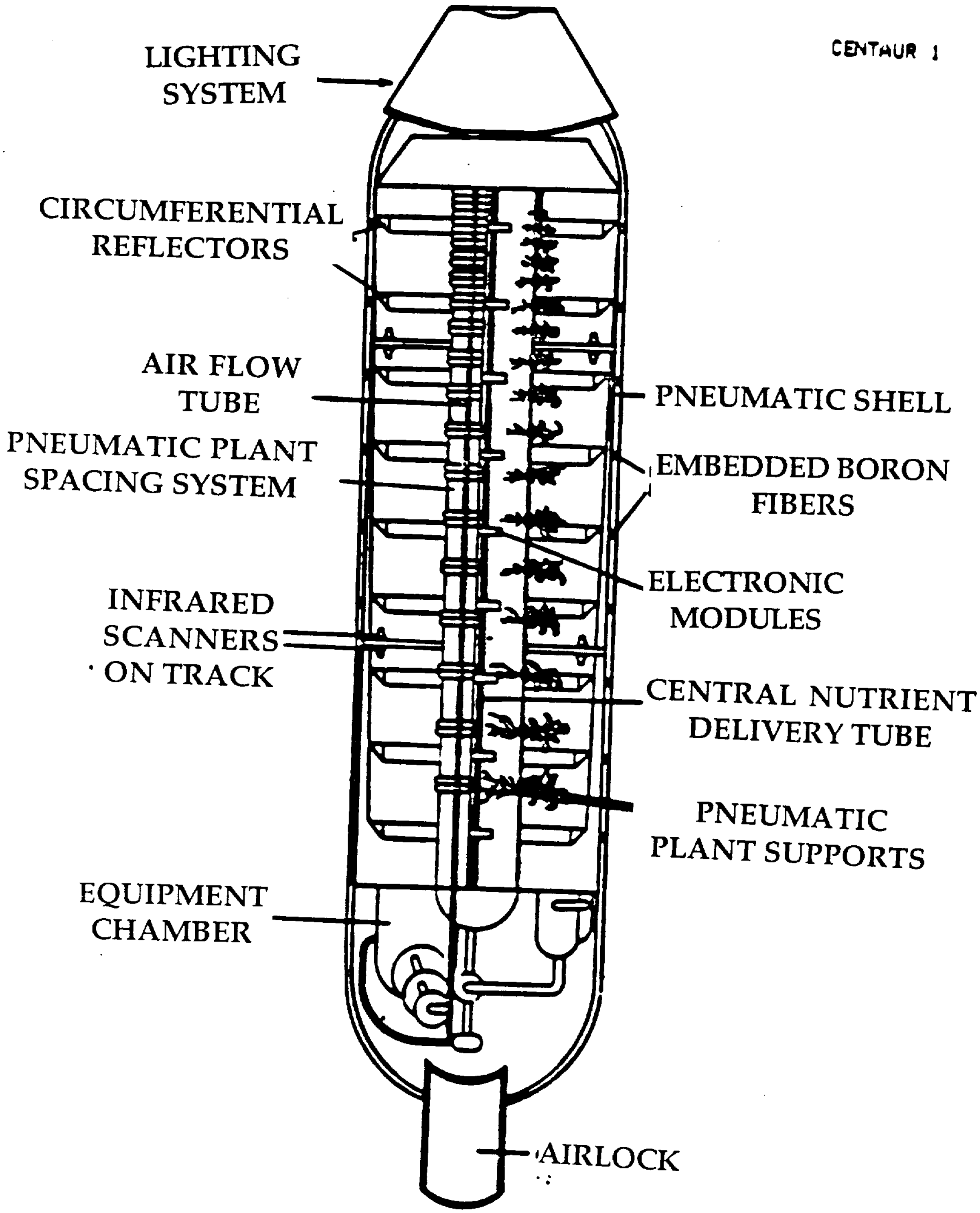


FIGURE 3G : ***CENTAUR I - A Space Gardening Concept***

(Regenerative System For Growing Higher Plants in Space, University of Florida, USRA Design Project, 1986) uncontaminated closed loop. The major difficulty realized with a space garden is the plants' inability to reproduce in space. It has been suggested to provide the station with plant seeds when necessary to start a new garden. Or the possibility of research providing a solution to the plant's lack of regeneration is always existent. With the concerns realized and solved, it becomes quite viable to set a lunar station up with a regenerative life support system.

CONCLUSION

6.1 Summary

In order to determine the "best overall" processes to be accomplished on the station, it must be defined what "best overall" means. This consists of the criteria by which the processes are decided. The three factors of the criteria are the materials needed for processing, the cost of production and worth of the finished product, and the aid it provides to set up a self-supportive station.

After exploring the diverse range of possibilities available for the station's processing, three were chosen. They include the production of fiberglass, growing crystals to be used as semiconductors, and a space garden. These processes benefit by being conducted in space and achieve better quality products than could be made on Earth.

6.2 Interpretation of Suggestions

The production of fiberglass, growing crystals, and a space garden were selected, because they fit the established criteria. With the production of fiberglass, the manufacturing can be completed using only lunar soil. The soil can easily be transported to the station from the base. The resulting fiberglass has many applications and can be used on the station, the base, or sent back to Earth. Also the station and the base can be made more self-supportive if they rely on themselves for a construction material.

Growing crystals to be used as semiconductors can be completed using lunar soil as well. Semiconductors are worth a great deal of money so the station could see financial rewards with this operation. These ideas demonstrate that semiconductors do meet the assigned criteria.

The space garden fits well into the plan of the station but for slightly different reasons than the other two processes. Although favorable economical results can be attained, the major factor with the garden is that it can help to set up the space station with a regenerative life support system. In other words, setting up a space garden will assist the station in becoming self-supportive in areas of food, oxygen, and waste.

6.3 Recommendations of Processing and Solutions to Problems

As previously explained, the space environment is quite different from the Earth's. Consequently, any processing that is attempted in space will be unconventional to Earth standards. Processing methods used on Earth must be modified in some ways to account for the lack of gravity and ambient pressure. The general operations of processing were adjusted so that the selected storing the lunar soil in a holding tank after it has been transported from the base and smelting the soil in a furnace. The soil is then ready to be manufactured by the spinnerette method. This method was chosen for its simplicity, yet important changes are still needed to accommodate the microgravity environment. The first batch of fiberglass made must be discarded, because it includes non-uniform fibers. Next, the production run should not be submitted to any abrupt movements. This requires that the station not have any quick acceleration changes and that the station not dock during a run. Because the process would benefit by being performed in zero pressure, the method was redesigned to conform to that stipulation.

For growing crystals in microgravity, the Czochralski method was selected. After the material was obtained from lunar soil and purified by a general method, the crystal could be grown by altering the Czochralski method. Instead of using a crucible to hold the melt, a movable piston is used around the melt so the pressure can be regulated. A mask is also included in the process at the top of the melt. The purpose of the mask is to equalize the forces that are experienced by the melt as the crystal is growing.

The researched system of a space garden, CENTAUR, is adjusted so the space garden can be used as an agricultural process. Because this system has never been implemented, all types of problems will most likely arise. To plan for these, it has been decided to begin the garden as only a partial food supplier. Although the temperature, pressure, lighting, nutrients, and water will be regulated by computer, modifications might be needed in those areas also after the garden's implementation. Another concern of this process is contaminants invading the closed loop system. To prevent this, chemicals will be flushed through the system to kill any contaminants but will not be harmful to the plants or the humans. The major concern of this process is that research to date shows plants cannot reproduce in space. It is planned to continue research with this implemented space garden and possibly solve this problem. If not, the alternative is to have the plant seeds sent up from the Earth when the garden is ready to begin again.

As it has been discussed through this report, certain processes can benefit by being performed in a microgravity environment. The production of fiberglass, growing crystals for use as semiconductors, and a space garden are the chosen processes for the orbiting lunar station because they can benefit by the space environment and are compatible with the intentions of the station. The processes were modified in different ways so that they could be feasibly performed on the orbiting lunar station.

CHAPTER 4

Environmental Control and Life Support System for a Lunar Space Station

INTRODUCTION

The environmental control and life support system described below provides for a partial closure for our space station. Partial closure of the ECLSS is based on the processes for closing the air loop and the water loop. A completely closed ECLSS is not possible at this time because of the lack of knowledge concerning food development in space. Research into food development on our station will take place, but our crew will only be able to harvest a small amount of food. Therefore, the resupply of food is a must.

The partially closed ECLSS will contain modularity and flexibility in design, in order to accommodate on-orbit maintainability, repair and evolutionary growth capability. Therefore, the ECLSS equipment is located in a centralized/distributed manner, see Figure 4A, which minimizes the amount of hardware needed. This is known as the "common module" philosophy, which means that each module contains the same equipment.

AIR LOOP

The air loop begins with two externally mounted, high pressure storage tanks containing Nitrogen and Oxygen. The gasses are then sent through separate lines to be monitored by two high pressure atmospheric regulators. The gasses are next sent into the module, where they are mixed together in specific concentrations. The concentrations are regulated by signals from an oxygen pressure transducers located within the module. Once the gasses are mixed, a control system is used to keep module working conditions reasonable for the crew. This means that the temperature of the module is kept within a 18-27 degree celsius range, with 30%-70% relative humidity. Simultaneously the module total pressure is controlled by an Atmospheric Control System. This control system is connected to a nitrogen/oxygen control panel mounted within the module. This panel can be used manually for such uses as the repressurization of an airlock. This carefully controlled air can now be uniformally distributed through the use of adjustable air diffusers, which circulate the air into the module at a rate of 5-12 meters a minute. As this loop is closed, the air within the module is collected for recycling by fans mounted on the subfloor. The air, warmed by the crew and surrounding structure, is sucked through openings in the main floor, and any debris present is discarded at the inlet filter. The air immediately passes through smoke sensors at the fan inlet, as part of the warning system. If needed, the atmospheric control system is connected to fire suppression equipment available for immediate use. The air next passes through a carbon dioxide and contaminant process in order to keep the carbon dioxide level within safe limits. This process consists of lithium hydroxide cartridges for the carbon dioxide and activated charcoal for any contaminants and microorganisms. The carbon dioxide and contaminants are then sent to catalytic filters for further breakdown into useable elements. The following is a list of the elements created and where they are subsequently sent:

LIFE SUPPORT: Air Loop Design

LUNAR STATION

SYSTEM	LOCATION
Atmospheric Pressure and Composition	
1. Control panel for cabin pressure:	Local, wall.
2. Fire detection and supression:	Local, fan inlets.
3. Pressure regulators:	Local, wall.
4. Monitors of atmospheric conditions:	Centralized.
5. Sensors of atmospheric conditions:	Local, anywhere.
6. Pressure dump and relief valves:	Local, accessible.
Temperature and Humidity Control	
7. Heat exchangers:	Local, subfloor.
8. Fans:	Local, floor.
9. Noise mufflers:	Local, subfloor.
10. Diffusers for fresh air:	Local, ceiling.
Atmospheric Revitalization	
11. Carbon dioxide removal:	Local, subfloor.
12. Carbon dioxide delivery:	Centralized.
13. Oxygen generation:	Centralized.
14. Catalytic oxidizers/filters:	Centralized.
15. Monitors of above:	Centralized.
NOTE: LOCAL - in each module CENTRALIZED - one control modu	

FIGURE 4A

a) water - sent to interface with the water loop,
b) carbon dioxide - sent to the Agricultural Module for the plant use,
c) hydrogen - formed from the chemical reactions, and sent to the reaction control system,
d) contaminants - stored and eventually removed from the station.

Meanwhile, whatever is left from the air loop passes through a heat exchanger which cools the air below the dew point. The water which forms is then sent to interface with the water loop, while the nitrogen which is left is sent to the line coming from the external Nitrogen storage tank, and enters the air loop. Finally, pressure relief valves are mounted within the module to protect the structure against excessive pressure differentials, depressurization or evacuation of the module, and vent experiment chambers. See Figure 4B, which shows the air loop flow chart.

WATER LOOP

The water loop begins with the external storage of fresh water to be used solely for drinking purposes. The water to be used for all other utility purposes comes from the recycled water storage tank. Both the fresh drinking water and the recycled water lines are controlled by the water flow distribution system, which directs the particular water type to a specific destination. The next step in the water loop is to collect the water for recycling. The following is a list of where the water is collected for recycling:

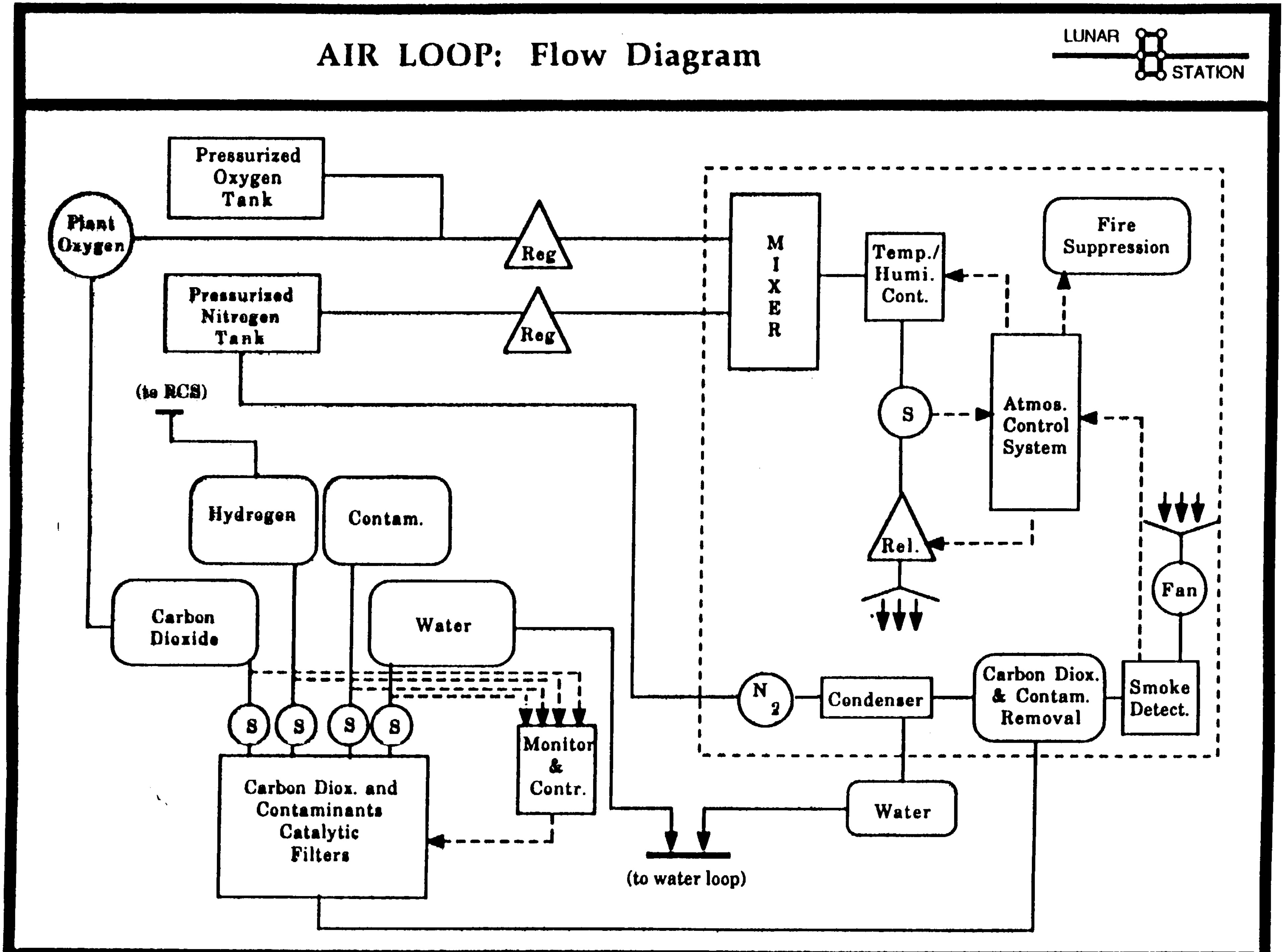
a) hygiene - urine/flush, shower and handwash,
b) potable - the water collected from the air loop, c) wash - dish and clothes water.

This water is collected and sent to a pretreatment process. This process consists of two parts, screens and/or filters and settling tanks. The pretreated water is then sent to the waste treatment facilities located on the station, and discussed under the waste loop section. This water is constantly being monitored for its quality and must meet a minimum standard before it is considered safe. Once the water is considered safe, it is sent into the recycled water storage tank.

In addition, a distillation facility is present on the station in order to transform the recycled water into clean, fresh water ready to enter the drinking water line. See figure 4C, which shows the water loop flow chart.

WASTE LOOP

On the station, there are two waste treatment facilities present, one in the Agricultural


AIR LOOP: Flow Diagram
LUNAR
STATION
Pressurized Oxygen Tank
Plant Oxygen
Reg
Pressurized Nitrogen Tank
Reg
MIXER
Temp./ Humi. Cont.
Fire Suppression
(to RCS)
S
Atmos. Control System
Rel.
Hydrogen
Contam.
Carbon Dioxide
Water
Fan
N2
Condenser
Carbon Diox. & Contam. Removal
Smoke Detect.
S
S
S
S
Monitor & Contr.
Carbon Diox. and Contaminants Catalytic Filters
Water
(to water loop)

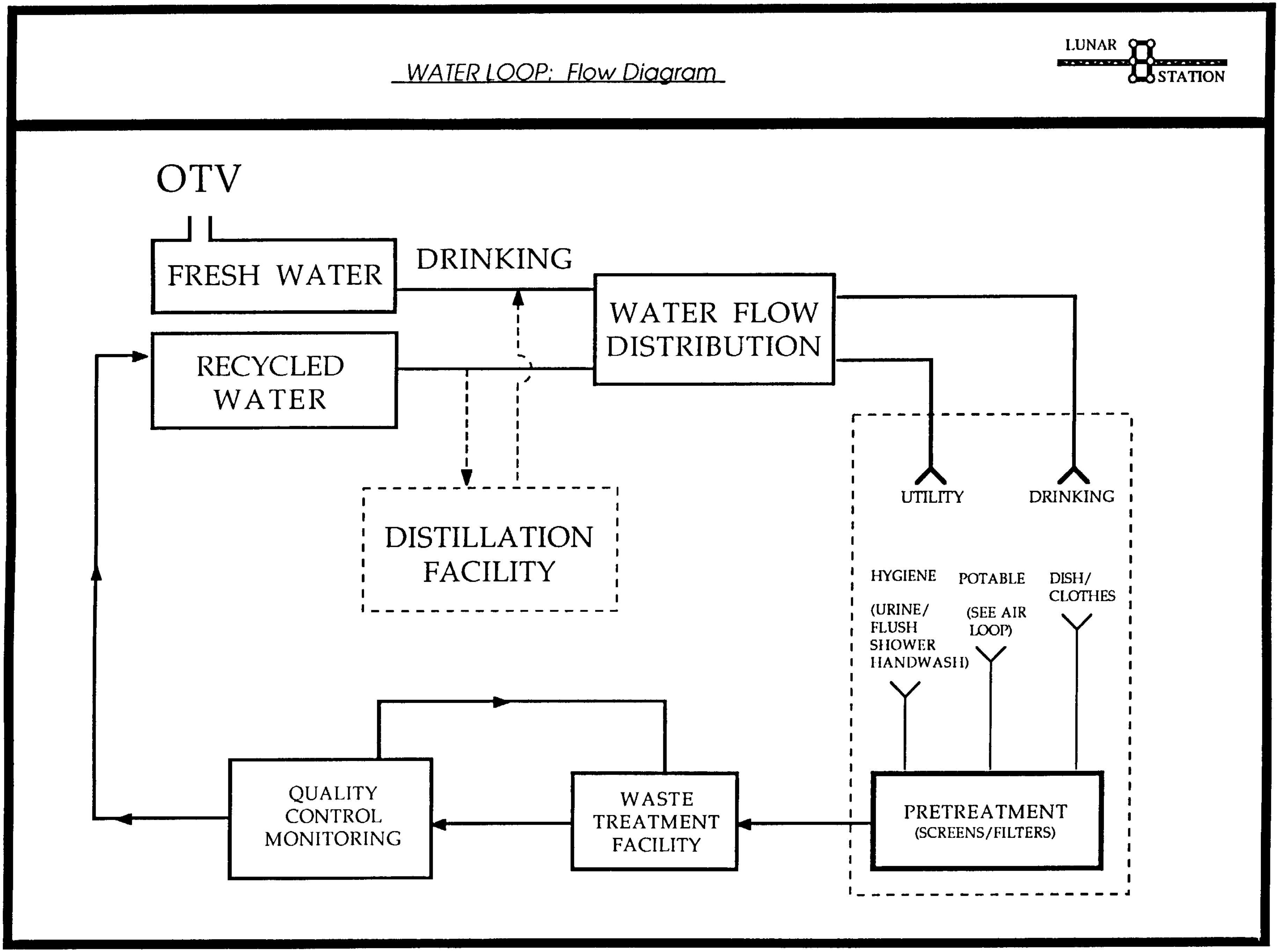

WATER LOOP: Flow Diagram
LUNAR STATION
OTV
FRESH WATER
DRINKING
WATER FLOW DISTRIBUTION
RECYCLED WATER
DISTILLATION FACILITY
UTILITY
DRINKING
HYGIENE
(URINE/ FLUSH SHOWER HANDWASH)
POTABLE
(SEE AIR LOOP)
DISH/ CLOTHES
QUALITY CONTROL MONITORING
WASTE TREATMENT FACILITY
PRETREATMENT (SCREENS/FILTERS)

FIGURE 4C

Module and the other in the Communication & Control Module. Both treatment facilities are modeled after existing waste treatment facilities found on earth, with allowances for advances in technology (size and efficiency), and are the same in all aspects except one. The facility in the Agricultural Module uses plants in the treatment process instead of aeration tanks. This is to allow for the research of a totally closed ecologically life support system. Please note that earth based waste treatment facilities use gravity to aid in treatment, while onboard the station, centrifuges will be used. After the waste water passes through the settling tanks of the pretreatment facility described in the water loop, the wastes are separated into solid and liquid parts. The liquid parts then proceed to go through the following steps, while at each step the heavier solid wastes are delivered to the solid loop to be discussed later:

a) aeration tank - in which air is blown up through the liquid waste in order to
or plant digestor - separate the waste into parts, heavier and lighter than the water. alternately, plants will be used to digest the heavier parts of the liquid waste.

b) clarifier (mechanical and chemical) - in which liquid waste is circulated around a tank with scoops and the solid wastes are forced to flow out the bottom while the liquid wastes flow out the top. Chemicals are being used at this time also, in order to break up the solid wastes.

c) gravity and carbon filters - the liquid wastes are forced down, using a centrifuge, through layers of sand and carbon.

d) chlorine treatment - the relatively clean liquid which remains, is treated with chlorine and sent back to the water loop for quality control monitoring.

Meanwhile, the solid wastes from the settling tanks and the other steps are sent into a tank in which a special chemical is added. This chemical is called a gravity thickener, and it allows the solid wastes to coagulate. This gel is then sent to filter presses in which it is compressed at very high pressures. Finally, this compressed solid waste, which is full of methane, is sent to the furnace where it acts as a fuel and it is subsequently incinerated. See Figure 4D & E, which shows the waste loop flow chart.

REFRIGERATION SYSTEM

The function of the refrigeration system will be to provide storage for perishable food and biomedical samples and to chill drinking water. The freezer compartments will consist of a food and

LIFE SUPPORT: Waste Loop

LUNAR STATION

PRE-TREATMENT

-Screens
-Settling Tanks

WASTE TREATMENT

LIQUID

- Aeration or Plant Digester
- Clarifier (Mechanical & Chemical)
- Centrifugal & Carbon Filter
- Chlorine Treatment

SOLID

- Centrifugal Thickners
- Filter Presses
- Incinerator

Note: Capacity-400 gals / day

FIGURE 4D

SOLID WASTE LOOP: Flow Chart

LUNAR STATION

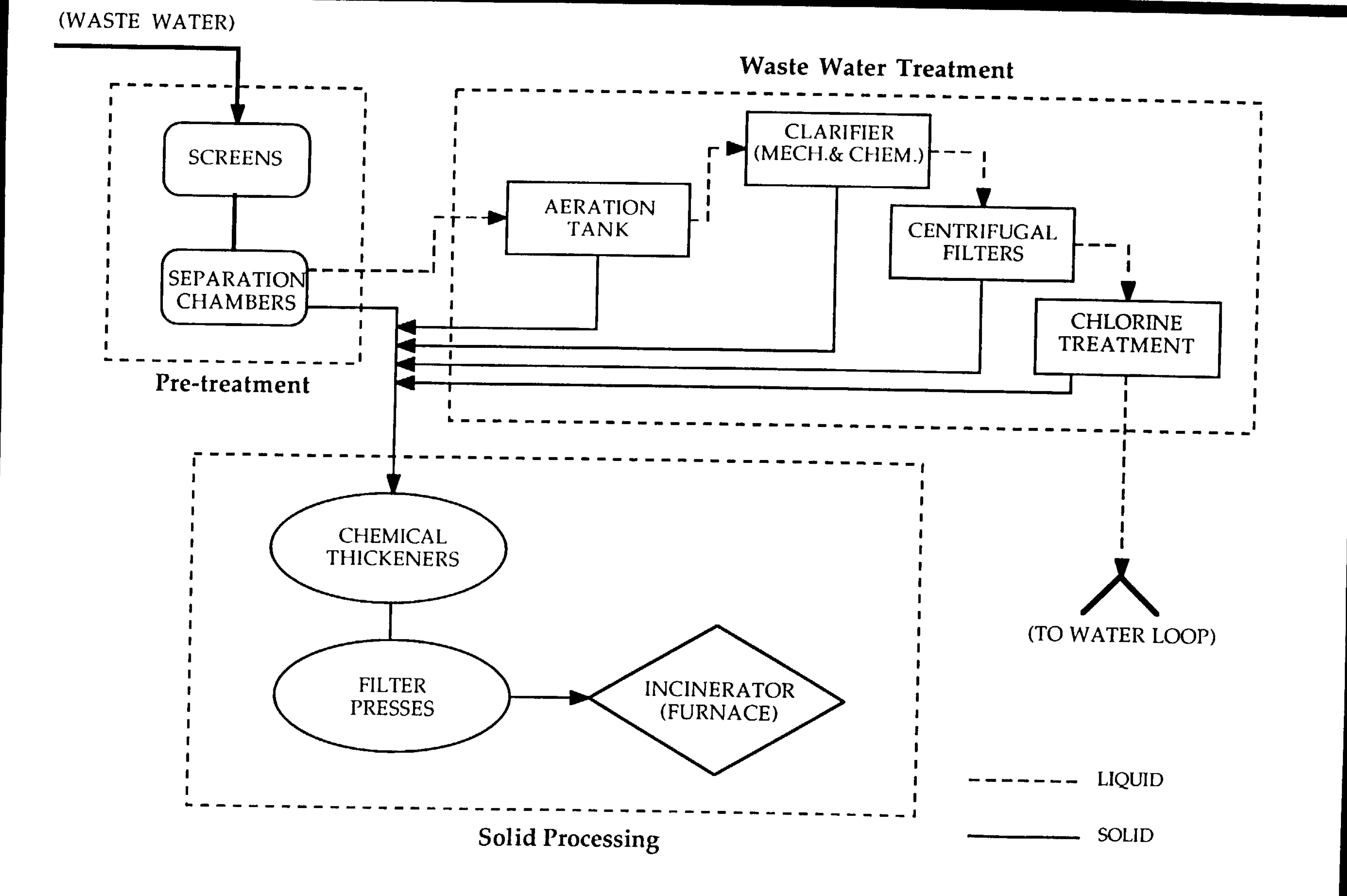


FIGURE 4E

water chiller. The entire cooling circuit will be redundant for reliability. In this cooling circuit, Freon 21 will be used as the heat transport fluid, due to its thermal properties for the extreme orbital thermal environment. Each loop will consist of three main sections; the heat rejection section, the freezer section, and the chiller section. Within each loop, the coolant will flow in series through the wardroom food freezer and food storage freezer. The coolant will then be warmed slightly before passing through the food and water chillers. The heat rejection system will interact with the water cooling loop, which collects all module heat loads and transports them to the exterior of the station for final rejection, by way of a heat exchanger (see reference 1).

EVA EQUIPMENT SERVICING

Extravehicular Mobility Unit (EMU) and Manned Maneuvering Unit (MMU) servicing will be a function of our station life support system. Replenishment of EMU and MMU expendables and the recovery of waste products will be provided. The air loop will supply oxygen while the water loop will supply water for the EMU's. The waste loop will reprocess the collected waste water while the air loop will reprocess the collected carbon dioxide. The air loop will further provide nitrogen for MMU propellant system recharging, and generate make up gasses for airlock/hyperbaric facility leakage and pressurization as well as atmosphere revitalization and cooling for pre-EVA activities (see reference 2).

References

1. Hopson, Littles, Patterson, Flight Operations And Performance Of Skylab Life Support And Environmental Control Systems. NASA technical report p. 222.

2. Engineering and Configuration of Space Stations and Platforms. NASA technical report .

CHAPTER 5

SPACE HAZARDS
AND
EMERGENCY LIFE SUPPORT

INTRODUCTION

In the design of any manned space vehicle or complex, a number of external and internal safety hazards that may endanger the crew must be considered. In the case of a permanently manned space station, meteor strikes and prolonged radiation exposure are the primary external hazards, while the internal hazards are generally associated with the equipment, experiments, and processes carried on board.

Any of the hazards stated above could lead to situations that would endanger the safety of the station crew.

EXTERNAL HAZARD

Background:

Meteorite strikes pose the greatest hazard to space missions of long duration. Meteorites can be classified into three types: aerolites, siderites, and siderolites. The aerolites are low density "puffballs" made primarily of stony material and form the majority of the meteor population. The siderites are made primarily of iron or nickel alloys and constitute less then 10% of the meteor population, while the siderolites, made of stone and iron, constitute the smallest fraction of the meteor population.

The hazards from meteorite impact on a space station can be divided into two categories: surface erosion and penetration. Surface erosion is caused by the impact of low density meteorites, which characteristically have low cohesive strength and low kinetic energy. They tend to fly apart on impact which results in little or no damage to the station structure and are therefore not considered to be a safety hazard. Penetration, however, could result in decompression or disruption of vital control or life-support systems.

Chances of a strike by a meteorite large enough to immediately disable or destroy a station have been calculated to be less then one in one million and therefore are of little concern. Micrometeorite strikes, however, are common and can be expected to occur at a rate of at least one per square centimeter per month. It has been determined that meteorites ranging in size from 0.1 mm to 1 mm are the most hazardous because of their high frequency of occurrence and high velocities, which ranges from 15 km/sec to 75 km/sec.

Solution:

The danger from micrometeorite strikes can be neutralized by the use of a multi-layered meteoroid shield consisting of a thin outer sacrificial bumper sheet and two inner back-up sheets. A number of experiments have been done using only one sacrificial sheet, however, given the wider range of meteorite sizes and velocities it is has been deemed necessary to use more then one sheet.

If the shield works correctly, the incoming meteorite, along with some of the first bumper sheet, is vaporized and is sprayed backward in an expanding conical cloud of debris moving in the original direction of the meteorite. This cloud of debris is then met by the second sheet, which is designed to break up any remaining particles that may possibly cause damage to the station. Finally, any remaining debris is vaporized by the last sheet before it can reach the station's pressure hull. In order for this process to occur properly, it is necessary for the sheets to be separated by a vacuum layer to allow the debris clouds to expand to a sufficient area before they strike the next layer of shielding.

It has been determined that the use of a woven, wire mesh bumper sheet is preferable to the use of a solid material bumper sheet. This is because the density of the sacrificial sheet has been determined to be directly proportional to the amount of damage done to the underlying surfaces. The lower density of a woven sheet greatly reduces the peak pressure upon impact with the underlying surface thereby causing less damage. The lower density also ensures a more complete vaporization since it more readily absorbs energy from the meteorite.

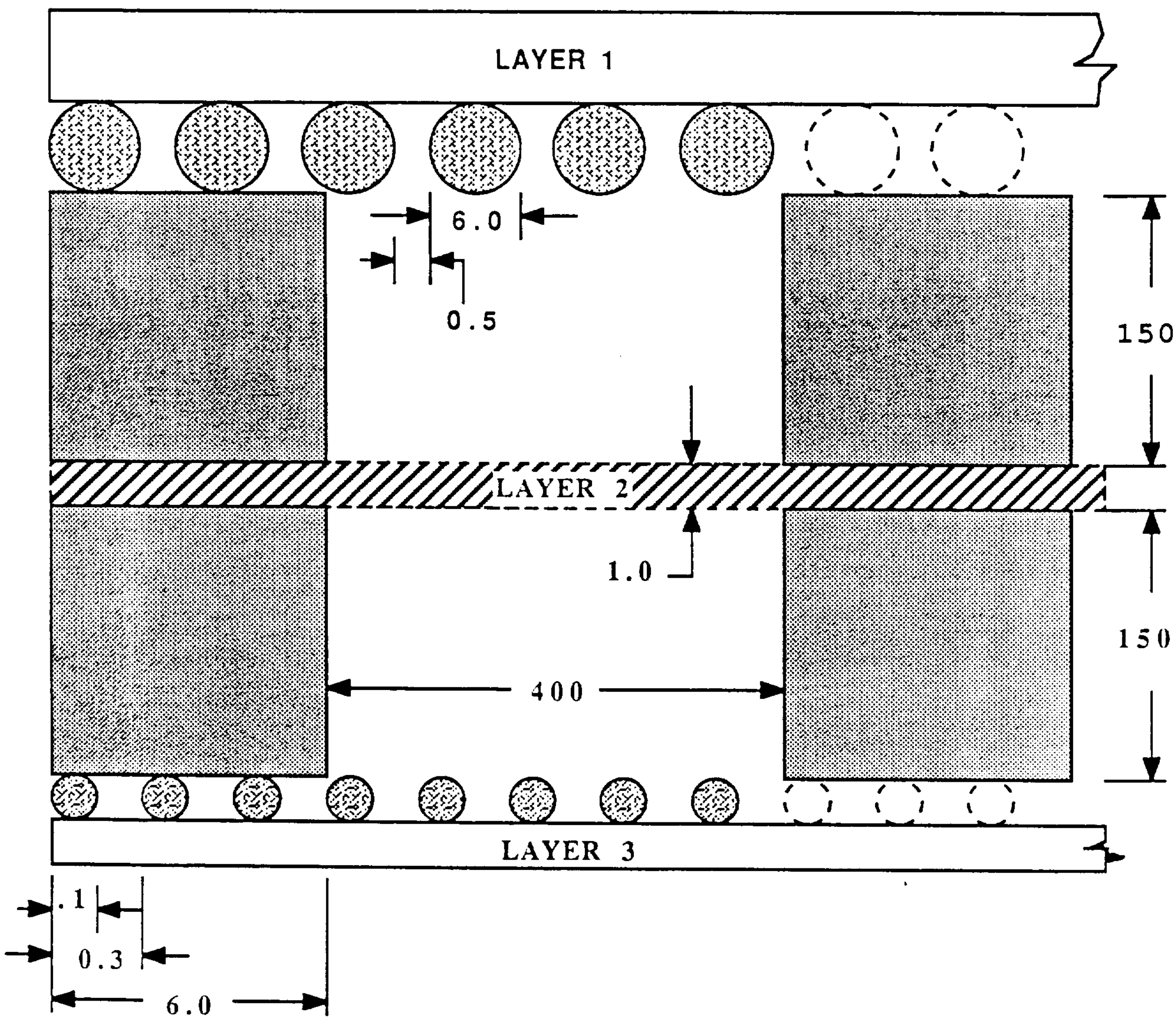
The density of the sacrificial sheets can be reduced by the use of a less dense material. However, the material used must able to withstand the harsh space environment, which includes extreme temperatures, very low pressure, and a high flux of penetrating and ultraviolet radiation. The material must also be made of a non-magnetic material to avoid problems with the station's electrical systems.

Mylar is a well suited material for use as a meteorite protection shield. Mylar, being a thermoplastic, has a relatively low melting point and therefore will tend to vaporize when struck by a high velocity projectile, which, as described above, is essential if the shield is to work properly. Furthermore, Mylar has a low vapor pressure and thereby does not evaporate quickly in the low pressure space environment. Also, Mylar has excellent radiation stabilization characteristics and will not be degraded by penetrating radiation. The only problem with Mylar is that, like all other polymers, it embrittles when exposed to ultraviolet radiation. This problem, however, can be eliminated by coating the Mylar with a film of aluminum, which absorbs or reflects the ultraviolet radiation leaving the Mylar untouched. This aluminization of Mylar will also help to protect the station from radiation exposure.

The design of the shield will consist of a first bumper layer of woven aluminum coated Mylar designed to pulverize particles up to 1 centimeter in diameter, a second layer of solid aluminum to absorb the resulting debris cloud and a third layer of woven aluminum coated Mylar to vaporize any remaining particles. Each mesh layer is separated from the adjacent layer by highly elastic Mylar springs. For the worst case scenario of a 1 centimeter diameter meteorite, moving with a velocity of 75 km/sec, it was determined that the first bumper layer thickness must equal 6 mm with a spacing of 0.5 mm between the mesh strands. The second solid layer was determined to be a 1 mm thick aluminum sheet, while the last layer was determined to require a thickness of 0.2 mm with a mesh spacing of 0.1 mm (see Fig 5A). It was further determined that the layers would be separated 15 cm from each other by 6 cm wide Mylar springs positioned 40 cm apart on center (see Fig 5B).

Given the determined dimensions, the total weight of the meteorite shield for one station module was found to be approximately 6000 kg broken down as follows: 5150 kg for the first layer, 600 kg for the second layer and 130 kg for the third layer.

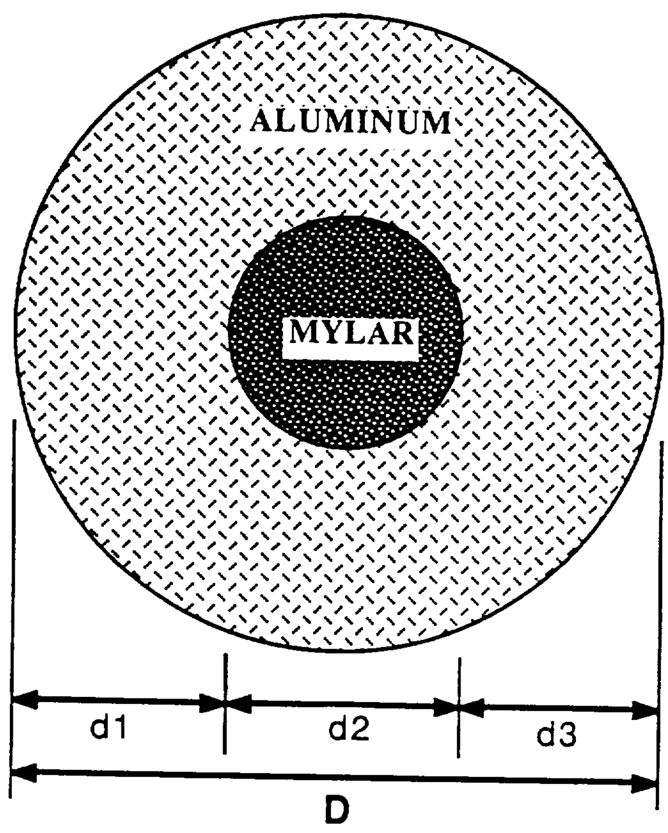
Meteorite Protection Using Meshes



* All measurements are in millimeters

FIGURE 5A

ALUMINIZED MYLAR STRAND (1ST AND 2ND LAYERS)



LAYER 1

d1=d2=d3 = 2.0 mm

LAYER 2

d1=d2=d3 = 0.07 mm

FIGURE 5B

INTERNAL HAZARDS

Background:

Equipment failure of any kind on board the space station could lead to potentially dangerous situations that would jeopardize the safety of the crew. These potential emergencies include biological or toxic contamination, electrical fire, chemical fire, general life support equipment failure, etc. The possibility of internally caused danger situations can be reduced by the use of detection sensors and alarms and by the use of functional redundancy in the design of station equipment and processes. In unmanned missions, the criteria for backup systems installed is cost effectiveness. In manned missions, the criteria must be crew survival.

Reliability and Safety Requirement:

In the design of the station, critical equipment must be designed to be at least Fail Operational/Fail Safe, while non-critical and highly reliable equipment (i.e. structures, pressure vessels, fluid lines, etc.) must be designed to Fail Safe. Each system must be designed to be restorable to operational status through inflight maintenance if failure was to occur. Equipment with high failure rates or short life spans will be considered for on-board replacement by spares which should be ferried on a 90 day resupply schedule to ensure the station can maintain full operational status at all times.

To fail operational requires that a system or subsystem must be able to maintain a specified performance level for 90 days following a single failure. Fail safe requires that emergency level performance must be provided for a 28 day period following a second failure. Fail safe operation therefore would be declared if the next failure would result in the loss of a critical function.

The environmental control and life support system (ECLSS) of the station should be divided into fifteen critical sub-systems:

Oxygen and Nitrogen Supply
Atmosphere Pressure and Composition Control Cabin Dump and Relief Systems
Fire Detection and Suppression
Contaminant Control
Trace Gas Analyzer and Atmosphere Monitor Carbon Dioxide Removal
Carbon Dioxide Reduction
Oxygen Generation
Heat Transport Loop
Cabin Temperature and Humidity Control
Condensate Collection and Processing
Urine Collection and Processing
Water Storage and Quality Monitor
Waste Processing

Furthermore, critical life support systems can be divided into two categories: local systems that are restricted to a single module and centralized systems that can be performed from a central location.

Local Life Support Functions:

A number of critical ECLSS functions can be isolated to a single station module including: cabin temperature and humidity control and subsystem support functions, such as the module coolant loop, oxygen and nitrogen supply lines, ventilation ducts, subsystem purge and relief lines and waste and potable water lines. Such local ECLSS systems need only be designed to fail operational, since fail safe capability is provided by the existence of multiple modules.

The importance of each of the module support functions is defined by the effect of its failure on any interfacing system. A level of redundancy must be incorporated to ensure a fail operational/fail safe condition exists for each support function. As a general rule, no single failure of a module support function should place the station in a fail safe situation. If critical equipment is distributed among the modules, less support equipment redundancy is required. Static components, such as fluid lines and heat exchangers would require no redundancy. Non-static equipment, such as regulators and pumps, would not require redundancy if the effect of the failure could be isolated to a single subsystem and the module is still habitable for the 90 day fail operational requirement. If the failure effects multiple subsystems, or the module is considered non-habitable, component redundancy must be incorporated.

What ever redundancy level is selected, all ECLSS equipment must be restorable to operational status at the next resupply interval.

Centralized Life Support Functions:

The amount and distribution of redundancy required to support functions which can be performed from a central location is determined by the need to accommodate for the complete failure of a station module. This requires that the approach selected must meet the 28 day fail safe requirement. The ECLSS must be capable of providing safe haven capability following a failure which would result in the loss of a module. To provide full safe haven capability following an ECLSS failure and the loss of a module, requires that either the critical ECLSS be distributed among the station modules or that the central support functions incorporate a level of redundancy comparable to the local support functions.

In general, the second method is preferable. For this method, two approaches are available: the replication of primary equipment, and the installation of an alternate technology backup system. The replication of primary equipment is acceptable only if there is no single failure mechanism which could induce a failure in all systems. A alternate technology system is generally used when that system provides a weight and volume benefit or when the primary processing equipment is vulnerable to a single failure mechanism.

Due to the diversity of the life support functions, their vulnerability to single point failures and possible design constraints, a single approach to redundancy is not possible. Tables 1 and 2 present the redundancy options available for a station with a six man crew.

Table 1 shows redundancy philosophies for a fail operational/fail safe system in which a safe haven situation is declared when the next failure results in a total loss of a critical function. Table 2 shows redundancy philosophies for a fail operational/fail safe/fail safe system in which a safe haven situation is declared when the next two failures will result in the loss of a critical function. In this scenario, the two failures can be two ECLSS failures or an ECLSS failure and the loss of a module. Tables 2 and 3 provide the flexibility to individually evaluate each of the subsystem functions against station constraints and to select the optimum approach.

Detection and Control Options:

The use of backup equipment to enhance crew safety and mission success is contingent upon the ability to detect and contain each failure. The station life support equipment, experiments and processes contain failure modes which, if allowed to propagate, could cause sequential failures in surrounding equipment and/or compromise crew safety. These failures could negate system redundancy if not detected.

Various detection devices must be implemented in the design of the station modules. These should include: pressure sensitive devices for liquid, gas and environment systems to detect possible pressure losses; mass spectrometers to detect toxic atmospheres and electrical fires; and thermocouples at key positions plus atmosphere measurements for oxygen changes to detect chemical fires. Smoke and other gas detection devices should also be located throughout the station. Finally, an active ventilation system and remote and portable fire extinguishers should be present.

Safe Haven Overview:

Safe haven capability calls for the outfitting of sections of the station with provisions, communication equipment and short term life support systems which would allow the crew to await rescue. Also, the safe haven sections should protect the crew from the heavy radiation exposure associated with large solar flares and allow for the control of the power and life support systems in other modules. In the case of the lunar space station, it has been decided that the two habitation modules located at the top and bottom of the station figure-eight complex will be outfitted as safe haven modules. The location of the safe havens was chosen to ensure optimum accessibility and ease of movement between modules (Figure 5C).

Individual safety options that can be found in the safe haven modules include spacesuits equipped with built-in life support and communications systems. These suits are also attached to Manned Maneuvering Units (MMU) to allow for ease of movement in extravehicular activities (EVA). Pressurized personal enclosures, or rescue balls, will also be stored in the safe haven modules. These balls are single-man, 39-inch inflatable spheres equipped with short-term life support and communications systems and are generally used for vehicle to vehicle rescue transfers.

Safe-haven design and specifications will be discussed further in a subsequent chapter. Please note that in this section, radiation hazard is not dealt with. For a more detailed analysis, please refer to the appropriate chapter on Radiation Shielding.

HABITATION MODULE LAYOUT

LUNAR STATION

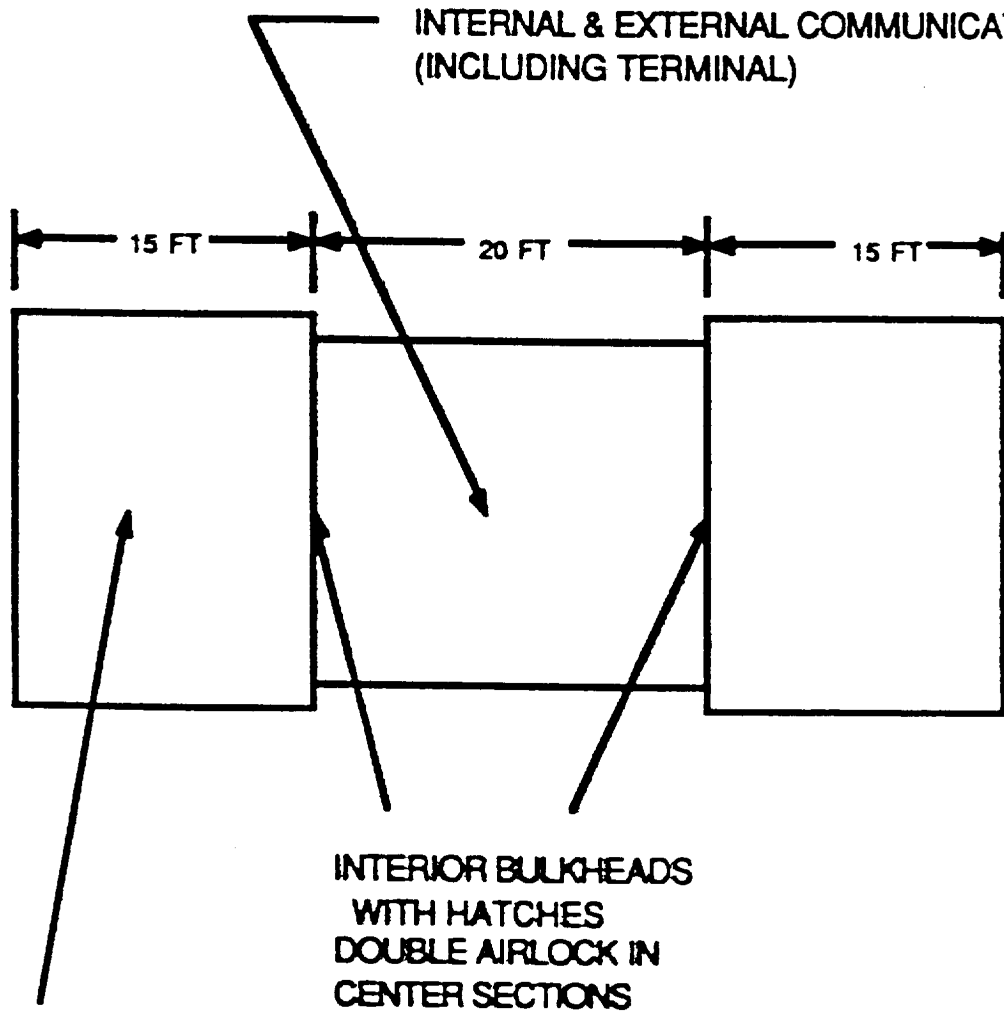


FIGURE 5C

CHAPTER 6

RADIATION PROTECTION

INTRODUCTION

Manned space vehicles outside of the geomagnetic field of the earth are subjected to the hazards of the unattenuated space radiation environment. The radiation comes in the form of galactic cosmic rays from deep space and solar cosmic rays from the sun. Both sources of radiation present a considerable health hazard to the occupants of a manned space vehicle, such as the lunar space station, if they are not properly protected. Inadequate radiation protection can result in discomfort, illness and in extreme cases, death.

Galactic cosmic rays represent a continuous radiation background in interplanetary space and consist of low intensity, extremely high-energy charged particles. They are composed of approximately 85% proton particles, 13% alpha-particles, and 2% particles of heavier nuclei. The flux density of the particles between the earth and the moon is between 2 and 4.5 particles per cm^2s^{-1} with energies of 10^8 to 10^{10} electronvolts per particle. They have an unprotected exposure rating between 4 and 12 rems per year due to their low flux (number of particles per unit time per unit volume) and consequently are not considered to be a real danger to station crew members.

Solar cosmic rays consist of high intensity, high-energy charged particles. They originate from solar flares and are composed of approximately 90% protons, 8% to 9% alpha-particles and 1% to 2% particles of heavier nuclei. The particle energies range from 10^6 electronvolts per particle, for minor flares, to 10^9 electronvolts per particle, for major flares. Because of its high-energy and high flux, solar cosmic radiation constitutes the principal radiation danger to station crew members and is therefore the primary factor when radiation protection is considered. Unprotected exposure to the radiation from a major solar flare could result in a dose of up to 600 rems per day, which is very close to the lethal limit of 650 rems per day. A rem being a unit of the radiation's biological effectiveness. This radiation threat is further compounded on long duration missions because of the integrated effects of radiation doses over a long period of time. Also the radiation shield must be designed so that secondary radiation, produced when the incoming electrons interact with shielding material to release high energy gamma rays and x-rays, is not a hazard to the station crew. Solar flares are generally associated with sunspots and are believed to be caused by a release of magnetic energy within the magnetic field of the sunspot. On the Sun's surface, magnetic fields are constantly moving in the violent motion of the sunspot groups and when areas with different magnetic properties collide and inter-penetrate, a rapid release of energy in the form of heat occurs and part of the Sun's mass, up to 10^{15} grams, is ejected into space. From the time a flare is visually observed on the Sun, it takes approximately 30 minutes for the radiation of highest energy to reach the vicinity of the Earth and Moon. This is followed by an exponential decrease in the radiation flux associated with a decrease in the particle energy over the next 48 hours.

Solar flares can be roughly classified into three categories according to the energy values of the emitted particles. High energy solar flares, with proton energies up to 15×10^9 electronvolts, occur approximately once or twice every five years. Medium energy flares, with a few particle energy values up to 10^9 electronvolts, occur about two to four times a year, while low energy flares occur about 10 to 12 times per year with energy values up to 100×10^6 electronvolts. Therefore, the shielding must be designed to effectively handle radiation levels up to medium energy flares because of their frequency and also reduce radiation levels of high energy flares.

Observational data has shown that in the 24 hours preceding a major solar flare, there are changes on the solar surface that involve the rapid motion of gases towards the center of activity, an increase in minor flares, a high rate of production of high frequency radio bursts and fast variations in the x-ray flux. Because of these variations in observable electro-magnetic radiation, it may soon be possible to predict major flares. Unfortunately, at this time predictions of flare radiation intensity and region of effected space cannot be made until a flare is visually observed. Until accurate predictions can be made, it will be necessary to provide the station crew with a protection system that is easy to use and available at all times. A number of methods for radiation protection can be considered applicable to this situation.

RADIATION PROTECTION METHODS

I. Electrostatic Shielding:

This method consists of the creation and maintenance of a strong electrical field around the space station, turning the station into a large electrical condenser. The incoming ionized particles (protons and alpha particles) would then be deflected away from the station by the electrical field. Unfortunately, the power required to encompass a station module 35 feet in length and 15 feet in diameter, would be in excess of 200*106 volts, which is far beyond the capabilities of the station. Furthermore, even if the power were available, the electrical field would leak away into space due to the presence of solar winds, which fill interplanetary space with approximately 10 particles per c.c. These particles act as conductors and draw off the electrical charges used to create the shield. It is also possible that the electrical field could disrupt electrical devices within the station. For these reasons, this method of shielding was not considered feasible.

II. Magnetic Shielding:

The magnetic shielding principle is similar in concept to the way the Earth's magnetic field deflects protons and electrons from their paths into a spiral about magnetic "lines of force." If the station could carry enough generating equipment, it could artificially generate a magnetic field, which would deflect the incoming radiation particles. This method is considered extremely well suited for large spacecraft and space stations and has the great advantage in that it can be switched on and off as needed. Another advantage of the magnetic shield is that it stops electrons completely thereby eliminating the possibility of secondary radiation. Unfortunately, if conventional magnets and materials are used, the heat generated with the field would probably melt the station modules. Using today's technology would also result in a considerable weight penalty over conventional solid shielding. Similar to the electrical shielding method, it is possible that the magnetic fields may 'leak' into the station and disrupt electrical devices.

If technology could be advanced to allow for the practical use of superconducting, refrigerated, alloy magnets, the field could be created without much heat generation and with no weight penalty. However, given the timetable for implementation of the station, it is highly unlikely that such advances could be made, therefore this method is not considered to be of use.

III. Plasma Shielding:

This system combines the two methods discussed previously. It depends on the containment of an electron cloud around the station by a magnetic field. In this method, the electrostatic shield problem of charge dissipation is solved by having the electrons gyrate along the field lines of an artificial magnetic field. The electrons are trapped in the magnetic field and cannot escape into space. The strength of the magnetic field required to deflect the incoming radiation, in comparison to the magnetic shielding method, is greatly reduced due to the presence of the (negative) electron cloud, which helps in deflecting the incoming (positive) protons. Consequently, there is a large reduction in weight since less generating equipment is required.

This system, though very promising for the future, cannot be practically applied presently. The main reason being that the stability of the electron cloud is still unknown. For proper radiation protection, the shield must have electrons travelling at speeds up to nine-tenths the velocity of light (0.9c) for the duration of a major solar flare (approx. 48 hours). This requires that the electrons be aligned with the magnetic field to an accuracy of one in 1012. It is not known if these requirements can be met at the present time.

IV. Solid Shielding:

Solid shielding is the conventional method used in radiation protection and simply requires the use of bulk radiation shielding of sufficient thickness to reduce exposure to protons and alpha particles to an acceptable level. This allows for easy construction, little to no maintenance and provides protection at all times. However, solid shielding is the also the most wasteful. It limits the useable space within the station modules, since the modules are limited to an outside diameter of 14 feet by the Space Shuttle bay, any increase in wall thickness would have to be added on the inside of the module. This also adds an additional weight penalty, by reducing the equipment payload that can be carried.

Even with these limitations, however, it was decided that this method, because of its simplicity in implementation and reliability, would be the most suitable in a lunar space station environment.

SHIELDING CONFIGURATION

The radiation shield will be integrated into the structural walls of the station modules. The pressure walls of the station modules will be designed with enough thickness to provide sufficient protection from low energy solar cosmic radiation (energies up to 100×10^6 electronvolts). The only limitation to wall thickness is the 24,900 kg (55,000 lb) lift capacity of the Space Shuttle. Therefore, it will be necessary to ensure that the pressure wall thickness results in a mass below 24,950 kg while still offering enough low energy protection for the station crew. Protection from medium and high energy solar flares (energies up to $1x10^9$ electronvolts) will be provided by "storm cellar" areas in the habitation modules. The "storm cellars" will be formed by attaching additional shielding, in a collar configuration, to the ends of the habitation modules. Each habitation module will have two "storm cellar" regions on either end, each 10 feet in length, giving the station a total of four "storm cellar" regions. The "storm cellars" will also be separated from the central region of the module by interior bulkheads to provide protection from incident radiation that penetrates through the central region of the module. In the event of a major solar flare, the crew will have approximately 30 minutes (the time required for flare activity to reach the moon) to retire to the "storm cellar" regions, where they will stay for the duration of the flare activity, usually 48 hours. The "storm cellars" will be equipped with rest and hygiene facilities, basic communications equipment, and a five day food supply for four people (see figure 5C).

Documentation concerning radiation exposure criteria and radiation protection criteria vary considerably from source to source. Considered acceptable exposure rates for astronauts on extended missions vary from 25 rem per year to 150 rem per year for blood forming organs and 50 to 600 rem per year for skin. In terms of rads (unit of radiation dose) the acceptable values range from 50 to 200 rad per year. This in turn effects the material thickness necessary to protect occupants of the station. Since the blood forming organs require the greatest protection, their allowable dosage is the determining criterion. Also, since the penetration range into a material of incident protons is much greater then the range of alpha particles with the same energy, effective reduction of proton exposure will be the determining criterion. From the mission scenario, it is known that each crew member will be on the station for a period of 90 days per year. Therefore, the radiation exposure per crew member per year can be reduced to a 90 day period.

There is general agreement, however, that materials with low atomic number are the most effective in stopping incident proton and alpha particles and the most effective in reducing the production of secondary radiation (see Figure 6A). It is also agreed that materials with higher atomic numbers are the most effective at absorbing secondary radiation and incident particles with heavy nuclei. These conditions can be satisfied by a combined shielding consisting of an outer layer with a low atomic number material and an inner layer with a high atomic number material. Polyethylene, because of its low atomic number, and aluminum, because of its lightweight and relatively high atomic number, have been determined to be materials with characteristics suitable for radiation protection. Other materials considered included lead, iron, zirconium, beryllium and graphite. However, these materials also have properties that make them unattractive in practical use, such as weight, high cost, toxicity, and scarcity. Using figure (6B) as a reference it was determined that an inner aluminum wall with a mass/area thickness of 6 g/cm2 in conjunction with an outer polyethylene layer with a thickness of 3 g/cm2 would adequately reduce crew exposure from proton particles with energies of up to 80*106 electronvolts. This gave an actual thickness of 3.33 cm for the polyethylene layer and actual thickness of 2.22 cm for the aluminum layer. Using the dimensions of the station

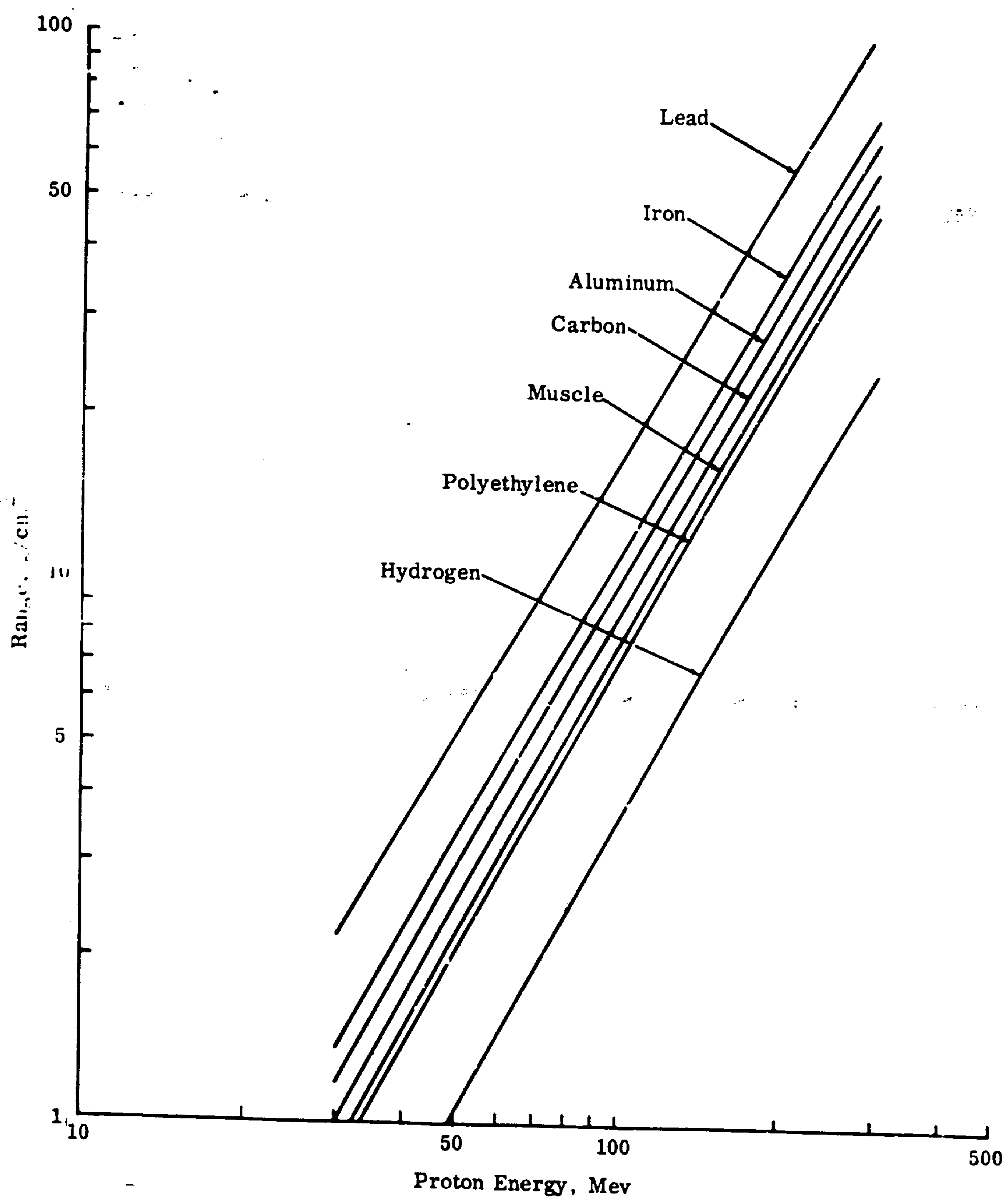


FIGURE 6A:

Effectiveness of Various Shielding Materials modules (length = 35 feet = 1066.8 cm, maximum outside radius = 14 ft = 426.72 cm) and the densities of aluminum (2.699 g/cm3) and polyethylene (0.9 g/cm3), it was calculated that the polyethylene layer would have a mass of 8505 kg and the aluminum layer would have a mass of 16400 kg. The total mass for the station modules would then be 24905 kg, which is within the lift capabilities of the Space Shuttle. It is believed that this pressure wall configuration, in conjunction with the micrometeorite shielding and other internal hardware, will provide more then adequate protection from low energy solar flare activity. Furthermore, it must also be remembered that after their service rotation on the station, crew members will be in a relatively radiation free environment for at least a nine month period, during which their bodies' will be able to recover from any radiation that they have been exposed to.

The additional "storm cellar" shielding had to be determined differently, since the maximum energy values in figures (6B) were considerably below the maximum energy values for major solar flare radiation. Instead, the shielding thickness was determined by maximizing the lift capabilities of the Space Shuttle. From the mission scenario, the "storm cellar" shielding will be launched using two shuttle flights, each flight carrying two shielding collars. This would allow each shielding collar to have a total mass of 12475 kg. Taking each collar as a hollow cylinder with an inside diameter of 14 feet (outside diameter of pressure wall) and a length of 10 feet, it was determined that each could be 5.58 cm thick if only aluminum was used. Using this as a reference and comparing it to information gained from other sources (see Figure 6C), it was eventually determined that a shielding collar composed of a 4.7 cm (4.2 g/cm^2) polyethylene layer and a 4 cm (10.8 g/cm^2) aluminum layer would provide adequate additional protection for the crew. In this configuration, the mass of the collar would be broken down into 8905 kg of aluminum and 3570 kg of polyethylene. The total protection afforded by the collar and the pressure wall in the "storm cellars" is then 6.17 cm (16.65 g/cm^2) of aluminum and 8 cm (7.23 g/cm^2) of polyethylene. These values compare favorably with those in Figure 6C. With the additional protection offered by the micrometeorite shield and internal hardware, the station "storm cellars" should more then adequately reduce the radiation exposure of the station crew during major solar flare activity.

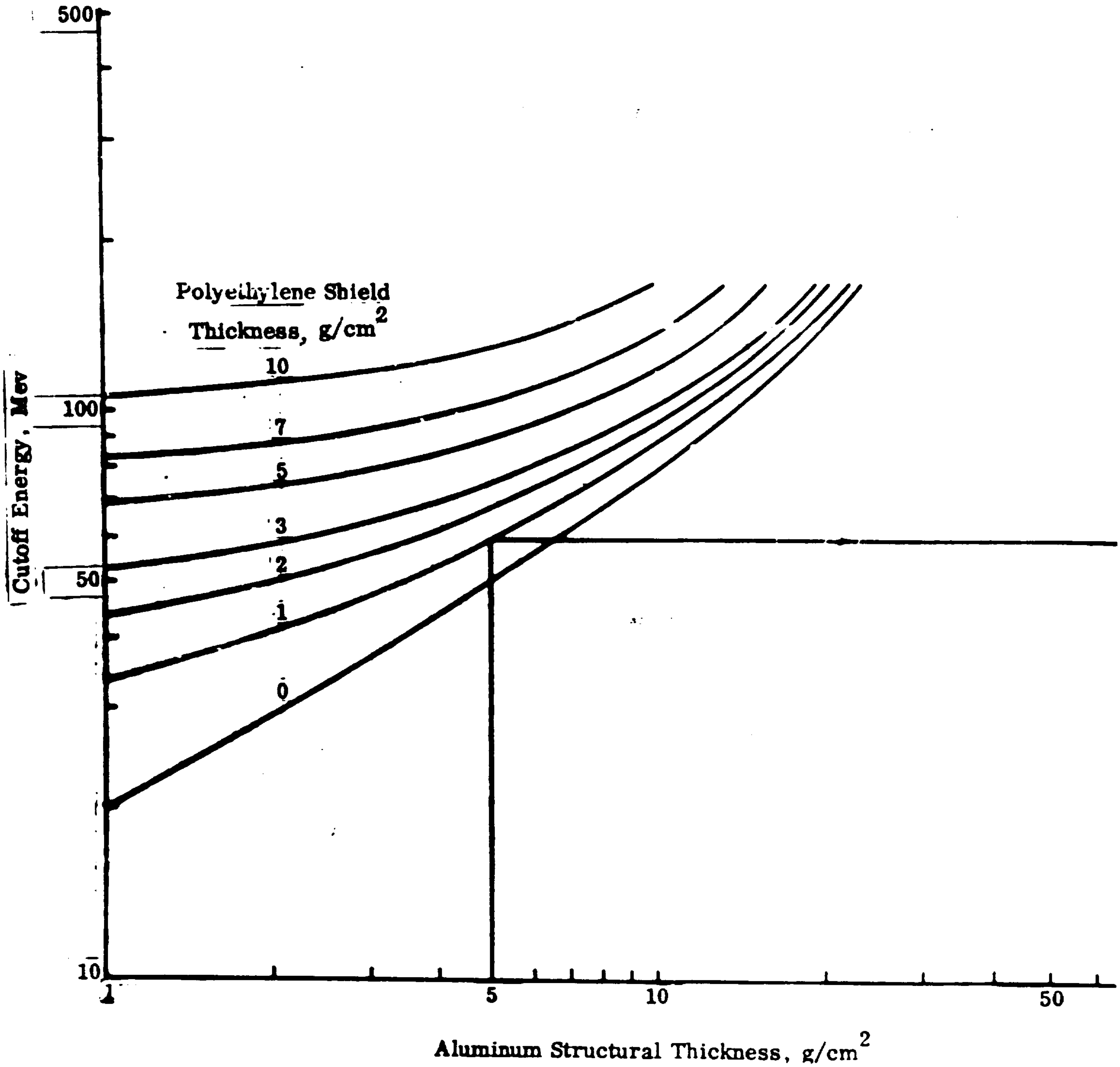

500
100
50
10
Cutoff Energy, Mev
Polyethylene Shield
Thickness, g/cm2
10
7
5
3
2
1
0
1
5
10
50
Aluminum Structural Thickness, g/cm2

FIGURE 6B

RADIATION PROTECTION FOR ALUMINUM 6061-T6

Mission Length (Days)	Exposure Rate (REM)	Mass/Area (g/cm2)	Thickness (cm)
10	25	10	3.70
10	50	7	2.59
20	25	20	7.41
20	50	10	3.70
100	25	40	14.82
100	50	20	7.41

FIGURE 6C

BIBLIOGRAPHY

Bobkov, V. G. and others. "Radiation Safety During Space Flights." NASA Technical Translation, Washington D.C. 1966.

Dye, D. L. and M. Wilkinson. "Radiation Hazards in Space." In Science Magazine, vol 147, Jan. 1965.

Genet, Michael. "Dangers of Radiation Exposure During a Manned Space Flight: Application to an Earth-Lunar Project." Ann Arbor: Scientific Translation Service, 1968.

Inman, R. A. "RF Radiation Hazards to Space Station Personnel." NASA Technical Memorandum, May 1970.

Kottler, Carl F. "Radiation Shielding Considerations for Interplanetary Spacecraft." NASA Scientific and Technical Information Facility, Jan. 1966.

Levy, Richard H. and Francis W. French. "The Plasma Radiation Shield: Concept and Applications to Space Vehicles." NASA-George C. Marshall Space Flight Center, Apr. 1967.

Linkous, R. E. and others. "An Experimental Approach to the Solar Cosmic Ray Hazard." Air Force Systems Command, Aug, 1964.

Molton, P. M. "The Protection of Astronauts Against Solar Flares." In Spaceflight, vol 13.

Schaeffer, Herman J. "Radiation Exposure From Heavy Nuclei in Solar Particle Beams in Space Systems of Low Shielding." In Aerospace Medicine, vol 137, Jan. 1966.

26 th Committee on Space Research Meeting. "Radiation Effects in Space." Toulouse, France, June 1986

CHAPTER 7

Physiological and Psychological Problems of Long-term Spaceflight

INTRODUCTION

The goal of this thesis project is to determine what we now know about ways to overcome the various physical and psychological difficulties which a space station crew will encounter during extended missions. The findings of this report are used in the design of a moon-orbiting, industrial station, where crew turn-around times are expected to be many months. Before presenting the problems and solutions of living in space, however, it is necessary to first outline the station design project as a whole in order to put this research effort into the proper context.

One of the projects of the aerospace design class AE 441-442 has been to design a space station. The station is intended to be an industrial manufacturing facility which will convert lunar soil into useful products such as fiberglass and silicon chips. The station will be assembled in lunar orbit and, once operational, will serve as a staging area for construction of a base on the surface of the moon. The orbital station will provide support to the lunar base, and will supply some of the materials necessary during its construction. After completion of both orbital and surface stations, the orbital station's mission will expand to include a variety of space manufacturing, such as zero-gravity crystal growing and alloying of metals. The station will also be used to perform research projects suitable to the lunar-orbit environment, such as studies of solar wind and radiation, which cannot be performed in Earth orbit because of the Earth's magnetic field.

The team designing the space station consists of seven members. Each is responsible for several design "specialties," such as radiation shielding, power systems, or life support. One of my areas of responsibility, and the reason behind this thesis project, is the research of any habitability problems likely to be encountered by the crew of this station and the recommendation of a solution or set of solutions to these problems.

There are numerous obstacles to successful extended space missions. Many of these are the result of the harsh conditions which confront those who must live in space. The absence of gravity forces, the presence of dangerous radiation, and the cramped and isolated living conditions found in spacecraft are all detrimental to the well-being and productivity of the crew. In addition to having to deal with these normal challenges of living in space, the crew of the AE 441-442 station will also face several unique problems caused by the lunar-orbit environment. The distance from Earth and the absence of the protection against radiation afforded by the Earth's magnetic field are two problems which are particular to this station. The space manufacturing mission of the station further compounds problems and requires that special consideration be given to station habitability. For example, the station must be laid out so that the negative effects on the crew of noises or odors from manufacturing operations are minimized.

This thesis will address the crew problems which must be taken into consideration for the design of this space station. Chapter II will deal with the problems encountered during short- term space travel, while Chapter III will address the effects of long-term living and working in space. Any factors which are unique to the station designed in AE 441-442 will be covered in Chapter IV. To conclude the report, Chapter V will summarize the specific difficulties and problems which most affect the design team's station, and will propose a comprehensive set of solutions to overcome these obstacles.

SHORT-TERM CONSIDERATIONS

The short-term effects of space travel are physiological in nature and become apparent immediately after liftoff. They are the result of the transition from the conditions on Earth to the zero-gravity environment found in space. They usually pose a problem only during the first week or two of living in space; after this time, the human body compensates for the new conditions and is able to acclimate to the situation. It is relatively easy to distinguish between the short-term and the long-term physiological effects, because long-term factors do not become noticeable until after several weeks in space. The major short-term problems of living in zero-G conditions are space sickness and fluid redistribution.

One of the immediate problems that has plagued many previous missions is space sickness. When first exposed to zero-gravity conditions, the human body receives conflicting sensory input, which results in disorientation. Symptoms of space sickness include nausea, vomiting, and lethargy. Though few cases have been serious enough to temporarily incapacitate the affected crew member, space sickness is a problem which must be overcome. Space sickness occurs when the sensory data from the semicircular canals of the inner ear conflict with the sensory input from the astronaut's eyes. The brain is unable to integrate the conflicting sensations, and the astronaut experiences spacial disorientation. In this way, space sickness is very similar to motion sickness in automobile or aircraft passengers. Space sickness is eventually overcome by familiarity with the sensation of weightlessness, and astronauts who have been in space on previous occasions usually do not experience the problem on subsequent missions. Strangely, astronauts who have experienced and overcome motion sickness in aircraft are not "immune" to space sickness on their first missions in zero-G. Space sickness would be nothing more than a recurring inconvenience if it were not for the host of secondary physiological changes that it causes. The major problem produced by space sickness is a state of temporary anorexia, during which the astronaut is unable to hold down food and experiences loss of appetite because of frequent nausea. This change in eating habits and the vomiting which often accompanies space sickness result in altered metabolism and causes body-fluid losses and electrolyte imbalances. Space sickness is interrelated with a series of other medical problems, such as hormone and electrolyte imbalances, all of which tend to compound each other and make the astronaut unmotivated and unfit.

Luckily, there are several factors which can lower the likelihood that an astronaut will succumb to space sickness. Astronauts in the Mercury and Gemini programs did not have serious problems with space sickness, whereas later Apollo and Skylab crews did. This difference was attributed to the small size of the earlier spacecraft, which severely restricted astronaut movement. Since space sickness is caused by conflicting sensations of motion, any factors which restrict crew motion will decrease the likelihood of spacial disorientation and onset of space sickness. Studies have shown that refraining from rapid head movements during the first few days in space will also reduce an astronaut's susceptibility to space sickness. From a design point of view, it is very helpful to have a definite "floor" and "ceiling" in the spacecraft. Even though these would not be required under zero-G conditions, their presence helps an astronaut maintain his orientation, and gives him a sense of which way is "up" and "down".

The best preventive measure against space sickness is the administration of drugs which inhibit motion sickness. These drugs can be taken orally about one-half hour prior to the mission if it is suspected that space sickness may occur. They work by numbing the semicircular canals and thereby inhibit the conflicting sensations which cause spatial disorientation. These drugs must be taken as a preventive rather than a curative measure, since they are administered orally and have little effect once an astronaut is actively sick. Unfortunately, some people experience drowsiness or lack of coordination when on this medication, so each case of space sickness must be handled individually. A combination of design features, motion restriction, and selective medication is the best solution to the space sickness problem.

The second short-term problem is also noticed immediately after liftoff and results from the redistribution of fluids within the body. Most astronauts experience a stuffiness of the head upon first entering zero-gravity conditions. It is similar to the sensation of hanging upside down for an extended period of time, and is due to the movement of fluids from the lower torso and legs to the head and upper body. On Earth, gravity normally pools fluid in the lower extremities, and the body is accustomed to this distribution. In zero-G, the fluid is free to move into the upper body, resulting in higher blood pressure in the head and a feeling of congestion.

Over a period of a few days, the body gradually eliminates this excess fluid and reaches a new state of equilibrium. Dehydration can become a problem, because the body has fewer fluid reserves with which to compensate for deviations in fluid consumption. Reduction of fluid volume and changes in fluid distribution within the body result in some electrolyte imbalances which could compound space sickness or other health problems. The body gradually adapts to the redistribution of fluids and adverse effects usually disappear after a week in space.

The most important concern about fluid loss is that of encountering difficulties upon return to Earth. During reentry, the force on the astronauts can easily exceed four times that of normal gravity. If the astronauts are in an upright or sitting position, this force tends to pull fluids into the lower body and legs. This change might be acceptable under normal conditions, but in the fluid-deficient condition of the crew, this loss of blood pressure to the head can result in gravity-induced loss of consciousness (GLOC). Periods of blacking out are obviously very dangerous and especially so during such a critical phase of flight. Fortunately, the GLOC problem can be overcome by a combination of solutions.

It is important for the crew to drink a lot of fluids prior to reentry to assure that everyone is well hydrated, since tolerance against GLOC is strongly influenced by fluid content of the body. A well hydrated astronaut can stand up to two extra G over one who is dehydrated. (A "G" is the measure of force equivalent to normal Earth gravity.)

A second solution is to use a G-suit similar to that worn by fighter pilots. A G-suit is a pair of pants which fits snugly over the legs and abdomen. Inflatable bladders within the G-suit are automatically pumped up during periods of high forces, serving to constrict the lower body and preventing fluid from pooling there. A properly worn suit can increase an astronaut's blood pressure enough to tolerate an extra G.

The third solution to overcoming GLOC is one of spacecraft design. Apollo astronauts had to endure sustained forces of up to six G, but were able to do so easily because they were in a supine position. Shuttle astronauts are subjected to about four sustained G, but are in a seated position which facilitates fluid pooling in the legs. In spacecraft designed so the crew is supine upon reentry, the astronauts are able to tolerate greater G forces because changes in head blood pressure are smaller. The short-term problems of spaceflight have been encountered repeatedly in man's past exploration of space. For this reason, these phenomena have been studied in great detail, and practical solutions to them have been developed.

When properly applied, the solutions outlined in this chapter can reduce these short-term problems to nothing more than minor inconveniences.

LONG-TERM CONSIDERATIONS

The long-term problems of living in space become noticeable after about two weeks in space and get more serious with time. Unlike the short-term difficulties that were discussed in the previous chapter, some of the long-term problems can persist for an extended period after return to Earth. Also, it is much more difficult to combat the many negative complications of extended living in space.

The most serious detrimental effects are the physiological changes caused by living in zero-G. Because very little muscle power is required to move about in this situation, the body begins to decondition and the muscles start to atrophy. Reduced ability for strenuous exercise is detectable in astronauts after as little as one week in space. Muscle atrophy through disuse continues to progress as time goes on, the leg muscles being the most strongly affected. This is because the legs are used all of the time on Earth, but are relatively unused in space. Most movement about the spacecraft cabin is done by pushing off with the arms and then floating.

Because of the zero-G conditions and general lack of physical activity, the body's cardiovascular system begins to decondition. The heart is not required to work as hard to circulate blood as it would on Earth. The muscle of the heart is therefore also subject to atrophy. The combination of muscular atrophy and weakening of the cardiovascular system can have serious consequences upon return to Earth. Soviet astronauts, who hold most of the records for the longest time in space, have often been too weak to walk upon returning from year- long space missions. When they were helped to stand, the astronauts sometimes lost consciousness because of the blood pressure drop caused by blood pooling in their legs. The astronauts had to undergo extensive physical training to regain their previous levels of fitness. After a year in space, it took over one-half year of strenuous training to regain pre-flight muscle and heart condition.

The major factor in decelerating the rate of muscle atrophy and cardiovascular deconditioning is crew exercise. About one hour per day of vigorous exercise can substantially retard the physiological consequences of living in zero-G. Exercise also releases some of the frustration associated with living for long periods in a cramped environment, and so has psychological benefits as well. Various lightweight exercise machines such as bicycles and treadmills have been adapted for application to the spaceflight environment. Most are collapsible as well as light, and so require very little storage space.

A problem similar to muscle atrophy is the loss of calcium from bones during extended zero-G. Although the loss of bone calcium is similar to the loss of muscle tissue in that lack of exercise contributes to both, the exact mechanism for bone decalcification is not well understood. It is believed that a complex series of changes in hormone levels, similar to that which produces the condition osteoporosis, causes the decalcification process. This loss of calcium occurs at an average rate of about 2% per month. Since humans can tolerate calcium losses of about 30% before bones become dangerously fragile, decalcification is not a serious problem on missions lasting on the order of one year. Calcium supplements are not very helpful in resisting decalcification, since the problem is one of body metabolism rather than lack of available calcium. Various drugs that inhibit calcium loss are currently under study, however, and researchers are optimistic that a cure for this problem will soon be available.

A problem which has been observed on spacecraft with atmospheres high in oxygen is a decreased count of red blood cells. In order to save weight, engineers designed some spacecraft with thinner skins, and this required lower internal operating pressures to avert structural failure. In order to achieve the same partial pressure of oxygen as in the Earth's atmosphere, however, the concentration of oxygen had to be increased. With these higher oxygen concentrations, red blood cells do not live as long. They are oxidized more rapidly and so must be broken down and rebuilt faster. This results in lower availability of mature red cells and greater rates of red cell death. Additionally, when the air is so rich in oxygen, an astronaut's red cell count rapidly decreases because fewer blood cells are required to carry the same amount of oxygen to body tissues. This is the opposite effect from that observed in people living at high altitudes; in some mountainous regions on Earth, the people have extremely high red cell counts because more cells are needed to carry oxygen when the air is so thin. Astronauts on long missions which used high oxygen atmospheres have found themselves short of breath upon return to Earth's 20% oxygen atmosphere. Muscular atrophy, cardiovascular deconditioning, and reduction of the blood's ability to transport oxygen can all combine to make an astronaut very unfit for 1-G activities. Fortunately, the problem of shortness of breath disappears over a period of a few weeks as blood cell counts return to normal. For extended missions, it is probably best to avoid using high oxygen atmospheres altogether, and instead employ a gas mixture closely approximating the Earth's atmosphere.

A major concern on any space mission, and especially those of long duration, is the intense radiation that can be encountered. The sun emits a continuous stream of high-energy particles and photons in the form of a "solar wind." Near the Earth, the charged particles in the solar wind are deflected and also captured in the large bands of the Van Allen Belt. These regions in space are especially dangerous because of their high radiation content. Space travelers are also subjected to solar- flare activity, during which a large burst of solar radiation is released. Radiation is obviously a factor in all regions of space.

The concern with high-energy radiation is that it penetrates into living organisms and causes tissue and genetic damage. Large doses of radiation will cause sickness and death within days or weeks, and so must be avoided at all costs. The damage caused by small amounts of radiation is much more subtle and may not become evident for several years. Small doses are cumulative over time, however, so exposure should be kept to a minimum. The way to protect astronauts against penetrating radiation is by "passive" shielding, placing a physical barrier between the radiation and the people. Normally, the Earth's atmosphere shields people against harmful radiation from the sun, but this protection is not available in space. Shielding for astronauts, therefore, must be constructed into the outer wall of their spacecraft.

In past missions of long duration, spacecraft were situated inside the influence of the Earth's magnetic field. The Earth's magnetosphere provided protection from the solar wind, so thick shielding was not required. Long-term missions outside of the magnetosphere will require a different approach.

Thick shielding will be required, but this would add greatly to the weight of the craft and therefore the cost of the mission. An alternative to this would be to use "active" shielding. By using a large electromagnet to generate an artificial magnetosphere around the craft, charged particle radiation would be deflected and the passive shielding could be reduced in thickness accordingly. The problem with active shielding is that it has not yet been fully developed, and would be economical only on very large spacecraft with large power supplies.

In addition to the variety of physiological problems to which astronauts are subject, there are several psychological considerations which must be addressed as well. Most of these arise because of the confinement of astronauts to the small environment of spacecraft. Internal volume is a scarce commodity, and engineers must give careful attention to the layout and other design considerations to assure that space is used effectively and with the best possible efficiency. On the other hand, each astronaut requires a certain volume to maintain personal health and sanity. On long-duration missions, designers must compromise between achieving efficient use of volume and satisfying the aesthetic needs of the astronauts.

Available volume is a very important factor for long-term habitability. Larger volumes give astronauts more space in which to move about and so prevent deconditioning of the body as well as allowing for more privacy. On long missions, privacy allows astronauts to get away from each other for short periods of time, and thereby lowers tension between crew members. Up to year-long studies in both 1-G isolation chambers and Earth-orbiting laboratories have determined that the absolute minimum acceptable volume is about 250 cubic feet per person. The optimal volume for confinements of year-long duration would be about 600-700 cubic feet per person.

Astronauts should have private sleeping areas, shielded from adjacent public areas by curtains or shades. Music should be available on an individual basis in sleeping as well as recreational areas. Computer work stations would allow astronauts to send electronic mail and keep notes or journals, or would provide entertainment during free time. Furthermore, the spacecraft must be laid out so that noise from work or recreation areas does not interfere with others' rest or sleep. An often overlooked habitability consideration is the use of colors in spacecraft. Color can be used to enhance visibility, cleanliness, and morale. Color scheme principles should follow aesthetic rather than pure utilitarian standards, and a room's color should suit the purposes of the room. Restful colors, such as greens, blues, and shades of brown should be used for places of relaxation. More saturated colors are suggested for work areas because they tend to stimulate. Some colors lend warmth to an area (red, yellow, brown), while others create a cool feeling (blue, green).

The need for some form of entertainment to pass the time increases with the duration of a mission. Individuals in long- term confinement tend to withdraw socially and participate in non-interactive recreation such as watching television or listening to music. It is important that sufficient recreational channels be available to satisfy this basic human need. During past space missions, food/water/waste management has been a problem. For purposes of promoting morale, food should be as close as possible to what astronauts are accustomed to on Earth. Eating out of "toothpaste tubes" may be adequate for short-duration missions, but is unacceptable in the long run. Experiments in the past have demonstrated that it is possible to grow food on spacecraft, and this appears to be a promising way of overcoming this problem. Also, drinking water must not taste of chlorine or be discolored. More attention must be given to the design of waste management systems. Present shower and toilet facilities are inconvenient to use and do not offer enough privacy.

LUNAR STATION CONSIDERATIONS

Whereas the previous chapters discussed universal problems encountered during all space missions, this chapter will address only those concerns which are specific to the space station designed in AE 441-442. Because of its unique location in lunar orbit and its industrial mission, the AE 441-442 station has some unique problems. There has never been a mission on or near the moon that lasted longer than just a few days, so most of the long-term habitability requirements have not been well defined for this type of mission. Additionally, this station is the first of its kind to attempt large-scale space manufacturing, and this raises habitability concerns which did not have to be considered before. Problems presented in this chapter are therefore extrapolated from information gathered during the short-term Apollo missions in lunar orbit and past small-scale attempts at zero-G manufacturing aboard Skylab and the Space Shuttle.

The station's lunar orbit causes a problem with communications. Since the station is in a near-equatorial orbit about the moon, it spends roughly one hour behind the moon during each orbit. When behind the moon, the station is out of contact with both ground control on Earth and the base on the moon. The effect of this loss of communication on the occupants of the station is uncertain.

In case of emergency, the station may be unable to get necessary telemetry support from Earth ground stations. Also, any entertainment being broadcast to the station would be subject to the hour-on hour-off schedule of the station's orbit.

The sheer distance of the station from the Earth poses problems of resupply and return back to Earth. The trip to lunar orbit takes about three days, so if some vital malfunction occurs, the station must wait at least that long to get spare parts or assistance from Earth. Because of the expense of maintaining a space manufacturing mission, an equipment "down time" of three days is unacceptable and should be avoided if possible. Spares must therefore be provided on the station for any mission-vital parts in order to allow for immediate repair. The voyage from the station back to Earth also requires three days. Consequently, in cases of medical or other emergency, the station cannot rely on any outside help for this time. If an emergency occurs on a spacecraft in Earth orbit, it could be back on the ground within hours at most. In lunar orbit, however, a simple case of appendicitis could become fatal. In the past, all long-duration space missions were conducted in Earth orbit, and this allowed a sick crew member to be returned almost immediately to facilities and care on Earth. This is not the case for a station in lunar orbit. Short-term lunar missions of the past had to gamble that no emergencies would arise, but for missions of longer duration, the chances of an emergency eventually occurring are greater. Manufacturing operations conducted on board this station further increase the chances of injury to the crew. A good deal of consideration must therefore be given to the handling of medical emergencies. Knowledge about the conduct of emergency medical treatment in space is very limited. Simple procedures on Earth, such as blood transfusions, have not been done before in space. It will probably not be feasible to perform anything beyond the most minor surgical procedures in the zero-G environment. A crew member requiring serious help will have to be stabilized and returned to Earth. Depending on the nature of the operation required and the facilities available on the surface of the moon, it may be possible to bring the crew member down to the moon for treatment. At the very least, the space station will need to have the capability to handle emergency first aid and stabilize critical patients for transit to the moon surface or back to Earth.

The space station will need to offer the crew adequate long and short-term protection from solar radiation. The lunar orbit environment is outside the boundary of the Earth's magnetosphere, so large concentrations of charged particles will be encountered by the station. It is not feasible to use active shielding for the AE 441-442 station because the power requirements of this method are too high. Also, the strong magnetic fields involved in this type of shielding may have negative effects on the projects conducted within the station, or on the station inhabitants. Active shielding is still in the experimental stages and many problems still need to be solved.

Passive shielding will have to be used. The outer hull of the space station will need to be made sufficiently thick to deflect most of the radiation normally encountered. The protection equivalent to several inches of aluminum will be required. This shielding will handle the normal levels of background radiation found in lunar orbit.

Protecting the crew from radiation during solar flares is a main issue of concern. In the hours immediately following a solar flare, the station will confront much higher levels of radiation than are normally present. The shielding weight which would be required to cover the entire station is prohibitive, so only small areas of the station can be given this thick shielding. These "safe havens" must be immediately accessible and must contain all of the necessities which the crew may require over a period of a few hours. Upon receiving notice that a solar flare has occurred, the crew members will proceed to the nearest safe haven and "weather out" the solar storm.

Special habitability considerations arise because of the industrial nature of the station. One of the projects planned for the station is the production of fiberglass from lunar soil. This process requires the operation of a furnace and various rotating machines, some of which may pose hazards to the crew. Resorting to a high degree of automation may be a way to considerably reduce the danger associated with this operation. Unfortunately, there are few precedents for any manufacturing in space, and no previous large-scale attempts. Much research still remains to be done in the field of space manufacturing before it is possible to determine a best method. Regardless of the individual manufacturing processes chosen for production of fiberglass, semiconductors, or silicon chips, it is important that crew safety and well-being be taken into account. Noise from the work must not interfere with the sleep cycles of the astronauts. The threat of a fire is a great danger to all space operations, and a fire is more likely to occur when industrial operations are conducted. Fire detection and suppression equipment will be required depending on the hazard associated with each area of the space station. Also, some of these processes could produce noxious fumes, solvents, or other waste products which require special treatment to prevent harm to the crew. On Earth, it is necessary to have strict environmental and safety regulations for the handling of hazardous materials in industry. The need for a safe working and living environment in space is even greater since a crew would not be able to receive outside help in an emergency.

CONCLUSION

This thesis has examined several problems associated with living and working in the space environment. Specifically, the problems which have been addressed are those that would most likely pose the greatest difficulty to the inhabitants and the designers of the AE 441-442 space station. By keeping in mind the issues presented in this paper, those designing this and similar stations will finish with a safer, more habitable, and more productive project.

The habitability problems of space stations have been grouped into three major categories: short-term effects, long- term problems, and factors which are inherent to the specific mission of the station. To assure the development of a successful project, designers must always take into consideration short-term effects and the specific station requirements. On missions of significant duration, the long-term problems of space living must also be addressed. Since crew turn-around times for the AE 441-442 station are expected to be on the order of several months, all three of these habitability categories must be considered during design of the station.

The major short-term problems are irritations rather than severe dangers, but they nevertheless must be confronted. Space sickness can be countered by administering various medications and by restricting movement of the affected crew member. If allowed to persist, it will cause detrimental metabolic changes and electrolyte imbalances. The astronaut will eventually get acclimated to the sensations of zero-G and overcome space sickness regardless of treatment. To maintain the crew in peak condition, however, it will be best to prevent space sickness whenever possible.

Another problem immediately encountered by the crew is the redistribution of fluids to the upper torso and head. This will cause slight discomfort, but will not really become serious until reentry back to normal Earth gravity. The problem can be solved by making sure the crew is well hydrated and wearing G suits during their return to Earth. It is advisable for the astronauts to be seated in a semi-supine position to reduce the pooling of blood in the legs during reentry. Crew physical condition also has a large influence on G tolerance, so exercising to maintain fitness will also alleviate this difficulty.

The long-term problems of space living are much more significant than the short-term effects, and become more serious with time. The atmosphere of the station should be kept as close to normal as possible to avoid the drop in red blood cell count associated with living in a high-oxygen environment. The crew must be allowed at least one hour per day of vigorous exercise to reduce the muscle atrophy caused by disuse. At the very least, a treadmill, bicycle, and simulated weight system should be available. Since they will be deployed only a few months, astronauts will not experience significant bone decalcification. Exercise is very important because it is not only the best way to reduce both muscle atrophy and calcium loss from bones, but it also has numerous psychological benefits as well. The radiation hazard to the inhabitants of the station is significant, but can be overcome. Shielding will be required against the normal background radiation found in lunar orbit. This is easily provided by the hull of the station. The major problem is posed by the periodic solar flares. Since weight requirements preclude shielding the entire station from this radiation, protected safe havens are required. Food, water, entertainment, and other necessities should be available for the crew for the few hours they must spend inside during the periods of peak radiation. Several safe havens will probably be required throughout the station to allow immediate access from any area.

Negative psychological effects can be overcome by providing a living and working environment which is as close to that on Earth as possible. Food must be appetizing, and should be supplemented with fresh fruits and vegetables brought from Earth or cultivated on board. Color schemes of an aesthetic rather than purely utilitarian nature should enhance visibility, cleanliness, and morale. The crew should also have access to several forms of entertainment. Games which stimulate crew interaction can be provided. Of equal importance, however, is the option for a crew member to withdraw and spend some time in privacy. It would also be beneficial for the station to be equipped with television/music entertainment channels for which crew members can make special requests for music, movies, or television programs.

The station's location and mission pose several unique problems. One or several lunar satellites may be required to provide uninterrupted communication and navigation for the station. Emergency capabilities on board must be such that the crew can adequately handle any situation without outside help for three days. Spares should be provided for any mission- critical parts which have high failure rates in order to allow for uninterrupted manufacturing. A medical facility will be needed to deal with medical emergencies until the affected astronaut can be brought to Earth. It should be possible at all times to evacuate the crew down to the moon surface base on short notice (a few hours). The station will ideally also have assistance from Earth available at all times with three day's notice.

Many of the habitability factors of the station have never been studied before, or have not been researched in adequate detail. Fortunately, the American space station which NASA plans for near future Earth orbit will be deployed before any moon- orbiting station. The NASA Space station "Freedom" will without a doubt serve as a test-bed for the processes and designs of future space activities, and will eventually answer the remaining habitability questions which still shroud the AE 441-442 station.

SUPPLEMENTAL READING

Coblentz, A., E. Fossier, G. Ignazi, and R. Mollard. "Habitability Design of European Spacecraft Hermes - Ergonomic Aspects." In 37th Congress of the International Astronautical Federation. New York, New York: International Astronautical Federation, 1986.

Forsyth, Donelson R. An Introduction to Group Dynamics. Monterey, California: Brooks/Cole Publishing, 1983.

Gazenko, O. G., E. B. Shulzhenko, V. F. Turchaninova, and A. D. Egorov. "Central and Regional Hemodynamics in Prolonged Space Flights." In 37th Congress of the International Astronautical Federation. New York, New York: International Astronautical Federation, 1986.

Goeters, Klaus-Martin. "The Recruitment and Organizational Integration of Space Personnel." In 37th Congress of the International Astronautical Federation. New York, New York: International Astronautical Federation, 1986.

Hamm, Madeleine. "Living in Space: Home Sweet Home Goes Up, Up, Away." Houston Chronicle, 23 September 1984, p. 9.

Klein, K. E., B. J. Bluth, and H. M. Wegmann. "Assessment of Space Station Design and Operation Through Bioastronautics." In 37th Congress of the International Astronautical Federation. New York, New York: International Astronautical Federation, 1986.

Langley Research Center Staff. "A Report on the Technological Problems of Manned Rotating Spacecraft." NASA Technical Note. D-1504 (1982): 135-141.

"Spatial Orientation in Weightlessness and Readaptation to Earth's Gravity." Science, July 1984, pp. 205-208.

Wise, James A. "The Space Station: Human Factors and Habitability." Human Factors Society Bulletin 29 (1986): 1-3.

Yost, Charles F. "Role of a Space Station in Materials Processing." In Symposium on the Space Station. Arlington, Virginia: AIAA/NASA, 1983.

BIBLIOGRAPHY

CHAPTER II

Connors, Mary M. Living Aloft: Human Requirements for Extended Spaceflight. Washington, D.C.: NASA Scientific and Technical Information Branch, 1985.

Hardy, James D. Physiological Problems In Space Exploration. Springfield, Illinois: Charles C. Thomas Publishers, 1987.

Lichtenberg, Byron K. "Vestibular Factors Influencing the Biomedical Support of Humans In Space." In 37th Congress of the International Astronautical Federation. New York, New York: International Astronautical Federation, 1986.

Linnarson, Dag, Bo Tedner, and Ola Eiken. "Effects of Gravity on the Fluid Balance and Distribution in Man." S-10401. Stockholm, Sweden: Karolinska Institutet, Departments of Medical Engineering and Environmental Physiology, 1986.

Sandler, H. "Zero-G Fluid Mechanics in Animal and Man." In Symposium on Microgravity Fluid Mechanics. pp. 41-43. Anaheim, California: American Society of Mechanical Engineers, 1986.

Thomson, Larry. "Being There... How the Body Can Adapt to Life Without Gravity." The Washington Post, June 12 1985, Health Magazine, p. 10.

White, Ronald J., D. B. Cramer, Joel I. Leonard, and W. P. Bishop. "Space Station and the Life Sciences." In Symposium on the Space Station. pp. 1-13. Arlington, Virginia: AIAA/NASA, 1983.

CHAPTER III

Bedini, D. "Space Station Habitability Study: the relation between volumes, shapes, and colors inside the space station and human behavior." In 37th Congress of the International Astronautical Federation. New York, New York: International Astronautical Federation, 1986.

Clearwater, Y. A. "Space Station Habitability Research." In 37th Congress of the International Astronautical Federation. New York, New York: International Astronautical

Federation, 1986.

Connors, Mary M. Living Aloft: Human Requirements for Extended Spaceflight. Washington, D.C.: NASA Scientific and Technical Information Branch, 1985.

Froehlich, Walter. Spacelab: An International Short-Stay Orbiting Laboratory. Washington, D.C.: NASA, 1983.

Gazenko, O. G., E. B. Schulzhenko, A. I. Grigoriev, O. Yu Atkov, and A. D. Egorov. "Review of Basic Medical Results of the Salyut-7 - Soyuz-T 8-Month Manned Flight." In 37th Congress of the International Astronautical Federation. New York, New York: International Astronautical Federation, 1986.

Hardy, James D. Physiological Problems In Space Exploration. Springfield, Illinois: Charles C. Thomas Publishers, 1987.

LaPatra, Jack W., and Robert E. Wilson. Moonlab. Washington, D.C.: NASA, 1968.

Pendergast, D. R., A. J. Olszowka, M. A. Rokitka, and L. E. Farhi. "Biomedical Support of Man in Space." In 37th Congress of the International Astronautical Federation. New York, New York: International Astronautical Federation, 1986.

Space Science Board. Human Factors in Long-Duration Spaceflight. Washington, D.C.: Nat. Science Academy, 1972.

Wensley, David C. "Interior Design of the U.S. Space Station Habitation Modules." In 37th Congress of the International Astronautical Federation. New York, New York: International Astronautical Federation, 1986.

White, Ronald J., D. B. Cramer, Joel I. Leonard, and W. P. Bishop. "Space Station and the Life Sciences." In Symposium on the Space Station. pp. 1-13. Arlington, Virginia: AIAA/NASA, 1983.

CHAPTER IV

Brown, Jeri W., and Nelson E. Brown. "Human Factors for Space Station." In 37th Congress of the International Astronautical Federation. New York, New York: International Astronautical Federation, 1986.

Clearwater, Y. A. "Space Station Habitability Research." In N37th Congress of the International Astronautical Federation. New York, New York: International Astronautical Federation, 1986.

Connors, Mary M. Living Aloft: Human Requirements for Extended Spaceflight. Washington, D.C.: NASA Scientific and Technical Information Branch, 1985.

Fedor, W. P., R. D. Waiss, and M. Baune. "International Commonality for Space Station." In 37th Congress of the International Astronautical Federation. New York, New York: International Astronautical Federation, 1986.

Grigoriev, A. I., O. P. Kozerenko, V. I. Myasnikov, and A. D. Egorov. "Ethical Problems of Interaction Between Ground- Based Personnel and Orbital Station Crewmembers." In 37th Congress of the International Astronautical Federation. New York, New York: International Astronautical Federation, 1986.

Pendergast, D. R., A. J. Olszowka, M. A. Rokitka, and L. E. Farhi. "Biomedical Support of Man in Space." In 37th Congress of the International Astronautical Federation. New York, New York: International Astronautical Federation, 1986.

Semyenov, Yu. P., and V. P. Legostayev. "Some Aspects of the Salyut-7/Mir Station Operations." In 37th Congress of the International Astronautical Federation. New York, New York: International Astronautical Federation, 1986.

Space Applications Board. Practical Applications of a Space Station. Washington, D.C.: National Academy Press, 1984.

Space Science Board. Human Factors in Long-Duration Spaceflight. Washington, D.C.: National Academy of Sciences, 1972.

Wensley, David C. "Interior Design of the U.S. Space Station Habitation Modules." In 37th Congress of the International Astronautical Federation. New York, New York: International Astronautical Federation, 1986.

CHAPTER 8

Orbital Mechanics and Communication

STATION ORBITAL MECHANICS

1.1 OVERVIEW

The position of the station in lunar orbit is dependant upon many factors. These include the need for easy access to the surface using the lander vehicle, minimizing the fuel required to transfer the station from low earth orbit, and the desire to minimize the need for attitude adjustments so as to provide the continuous micro-gravity needed for the production of crystals and fiberglass. By determining the effect that these requirements have on the orbit and performing a tradeoff analysis we have arrived at the plan that will be described here.

1.2 FLIGHT TO LUNAR ORBIT

The station parts; modules, nodes, etc. Will be boosted to low earth orbit using the current Space Shuttle, or any new variants such as the Shuttle C, that are developed before the beginning of the launch program. From a staging point in low earth orbit, the sections will be grouped together and attached to an orbital transfer vehicle for the flight to lunar orbit. Since construction of the station will be completed in phases, most of the sections needed for a single phase could be ferried using one or two OTV flights. These OTV's will probably be expendable and will not make the return flight to earth. For the transfer the sections will only be partially assembled, with the final assembly being completed upon arrival in lunar orbit. The OTV will arrive at the moon in an orbit inclined approximately 43.5 deg. to the lunar equator. This orbit will be circularized with a burn from the OTV's engines and a 23 deg. plane change will be performed to place the OTV into a circular orbit 200 km above the lunar surface and inclined at an angle of 20 deg. to the lunar equator with a period of 2.13 hours. This attitude was chosen because an equatorial orbit would require a 43 deg. plane change by the OTV which would be to costly in terms of propellant usage. Since the ground base will most likely be placed on the equator or close by due the extensive ground data possessed on that region, a 43 deg. orbit was ruled out because the lander would be required to perform a plane change during assent and descent. The 20 deg. orbit is a compromise between these two cases.

1.3 MAINTENANCE OF LUNAR ORBIT

Because of the low 200 km, orbit required for easy access to the surface by the lander. Constant adjustments will be needed to be made to correct for the gravitational disturbances caused by the unsymmetric nature of the moon. Additional adjustments will be required to keep the station in a proper attitude so that the solar arrays can receive the most sunlight. Accurate position will be determined through the use of onboard gyros and stellar position fixes.

1.4 ORBITAL ADJUSTMENTS

From the extensive tracking of the Apollo probes, it became apparent that the moon, as expected , was not perfectly symmetrical. There were mass concentrations that exerted tugs on the spacecraft at certain points in the orbit. Through careful tracking of the Apollo probes NASA engineers were able to generate a model of these mass concentrations in the band centered at the equator and extending 20 degrees above and below. This model was used to determine the first twenty or so terms in the orbit equation. This data along with any obtained from additional probes, is all that is available for the determination of the perturbations in the stations orbit.

For the estimation presented in this report, only the first seven terms were considered since the additional terms have only small effects and would only prove significant if the orbit was allowed to oscillate without corrections for a long period of time, days or weeks. This data, provided by NASA Goddard Space Flight Center, was input into the orbit equation and after a significant amount of calculations, a series of estimates were obtained. It was found that the influence of the mass concentrations would have an oscillatory effect on the stations orbit with the maximum variation over a one orbit (2 hour) path to be 0.5 kilometers. If left uncorrected this would accumulate into a variation of 5 kilometers after a period of 5 to 7 orbits.

This is a slight variation and would generally only require minimal correction. However, since the station is in such a low orbit, and it is necessary to maintain a constant altitude in order to facilitate rendezvous with the lander, we will need to correct for these oscillations.
A second variation in the station's orbit, the progression of the line of nodes. Will be caused by the rotation of the moon underneath the station. This progression will cause the station to pass directly over the lunar base once every 14.5 days. During this time, the lander will be able to launch directly into the stations orbit. At any other time the lander will have to perform orbital change maneuvers in order to intercept the station's orbit.

1.5 ATTITUDE VARIATIONS

The station will be subject to a gravity-gradient torque that will tend to align the station's axis of least moment of inertia perpendicular to the lunar surface. For this reason, the station will be aligned in a gravity-gradient stable position so as to avoid this problem. There a several factors however, that do not permit a perfect alignment in this position. First of all, since the lander will be docking with the station, the station's moments of inertia will change considerable while the lander is docked. Other factors that will contribute to variations in the moments of inertia are the transferring of fuel and soil to and from the lander, movement of the solar collectors, and additions to the station such as new modules. For these reasons it is necessary to provide the ability to make corrections in the station's orbit.

1.6 ATTITUDE CONTROL

In order to make the necessary corrections mentioned above, two systems will be provided on the station. Both systems will consist of thrusters located in packages around the central truss. For large orbital adjustments, there will be a total of sixteen hydrazine thrusters located at the four compass locations on the truss and pointed into and out of the plane of the truss. These thrusters are in redundant pairs. Only one of each pair will fire for each correction maneuver while the other will be used as a backup. Hydrazine was chosen as a fuel due to its high specific impulse and its availability. The fuel will be stored in a tank on the truss near the other fuel tanks and lines will be run from the tank to the thrusters. Hydrazine will have to be resupplied from the OTV.

For attitude control the station will use 48 hydrogen thrusters located in redundant pairs on each of the station primary axis. The truster packages will be placed on the central truss around the modules. This location was chosen over placement on the ends of the truss due to the problems with residue collection on the solar arrays and the bending moments that this would cause. Expanding hydrogen was chosen as a fuel because of the simplicity of the motor package and the abundant hydrogen contained on the station. While other propellants would prove more efficient, hydrogen was more convenient for this application.

1.7 ORBITAL CORRECTION PROCEDURE

The primary goal of the station is the manufacturing of materials in a micro-gravity environment. In order to maintain this as close as possible it is necessary to synchronize the firing of the thrusters with the processing onboard the station. In order to adhere to these requirements the following plan was adopted:

1. Major orbital adjustments will be attempted once a day, or once every 12 orbits. In this time the variation of the orbit is usually small. This will allow the processes to be synchronized around the firing schedule.
2. Attitude control will be attempted only when necessary and thrusters will be fired in small bursts so as to cause the least acceleration of the station. So the stations orbit will be allowed to drift from perfect by as much as allowable so that the processes onboard will have the most amount of time in micro-gravity possible.

SUMMARY OF ORBITAL MECHANICS

LUNAR STATION

1. ATTITUDE CONTROL:

   - TYPE - HYDROGEN THRUSTERS

   - NUMBER - 48 LOCATED IN REDUNDANT PAIRS

   - FUEL SUPPLY - PIPED FROM MAIN HYDROGEN STORAGE
   - LOCATION - ON CENTRAL TRUSS NEAR MODULES

2. ORBITAL ADJUSTMENTS:

   - CORRECTIONS WILL BE PERFORMED ONCE PER ORBIT

   - PRELIMINARY CALCULATIONS PREDICT ORBIT VARIATIONS OF <5 km FOR 20 ORBITS

   - THRUSTER FIRING WILL BE SQUENCED AROUND THE PRODUCTIONS CYCLES TO AVOID G EFFECTS

3. POSITION DETERMINATION:

   - POSITION FIXES DETERMINED BY ONBOARD GYROS AND STELLAR FIXES.

   - ESTIMATED ACCURACY IS WITHIN 5-10 METERS

COMMUNICATIONS

2.1 OVERVIEW

For any space mission, especially one of the magnitude of the lunar station, communications is of extreme importance, usually being a matter of life or death. For this reason the communications systems for the station must allow for accurate transmission of data, voice and image signals to and form the station with as much accuracy as possible. The entire system can be broken into three levels; station to earth, station to lander, and station to station. The methods and means of communications chosen for each of these areas are described in the sections below.

2.2 STATION-TO-EARTH

Station to earth communications is important because while the station will be autonomous to a certain extent, the final say in all mission critical matters will have to come from the planners on the ground. Communications is also necessary to schedule resupply missions and to provide a link with home for the astronauts on the station. To satisfy all of these requirements the station must be able to send and receive voice, image and data signals simultaneously if possible, thereby providing a real-time communications link.

These requirements will be satisfied by two 1.5 meter parabolic, omni-directional antennas that will be located on the truss of the station. Only one antenna will be required to meet the transmission requirements. The second one will serve as a spare or can be used to communicate with the lunar base or the lander if the station is in the appropriate orbit. The communications to earth will take place on the Ku transmission band.

Because the station will be behind the moon for a portion of the orbit, there will be a communications blackout for 37 minutes per orbit. This could be overcome through the use of relay satellites that could be placed so as to provide constant communications with earth. This option however was not chosen because it would be complicated and costly to place and maintain these satellites. If an emergency situation arises on the station during the blackout, Earth could provide very little help. A rescue mission would take days to arrive so the 37 minutes of blackout would not make much difference. During the later development of the moon such relay satellites may be needed and built. For the scope of this report however they can not be justified.

2.3 STATION-TO-LANDER

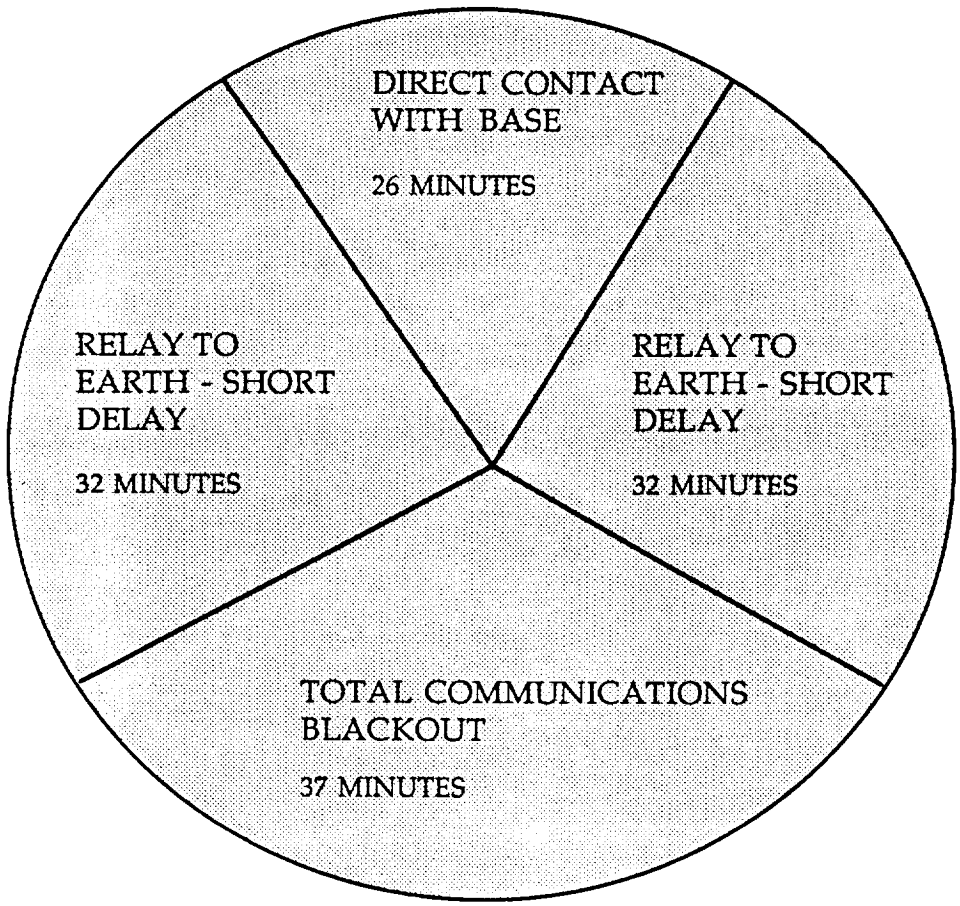
The primary communications needs of the station will be between the station and the lander vehicle and the lunar base. The lander will need position updates in order to plan a rendezvous with the station. The base will also need to be in contact with the station. In order to simplify the communications system, the same antennas used for the station-to- earth link will be used for this phase, along with the same transmission frequencies.

Ordinarily the base would only be able to be in contact with the station during the 26 minutes

ORBITAL COMMUNICATIONS

LUNAR STATION

1 ORBIT = 2 HOURS 7 MINUTES



COMMUNICATIONS FOR 24 HOUR DAY

TYPE OF COMMUNICATIONS	TOTAL TIME
DIRECT LINK	312 MIN. (5.2 hr.)
EARTH RELAY	768 MIN. (12.8 hr.)
TOTAL BLACKOUT	444 MIN. (7.4 hr.)

that the two will be in line- of-sight contact per orbit. Since the station and base will rely on each other considerably, this was not considered enough time. Therefore it was decided that once the station moved out of line of sight with the base communications will be relayed to the earth and then back to the base. This arrangement will provide an additional 64 minutes of communications per orbit, leaving only 37 minutes of blackout.

The earth relay process will include transmission of the signal from the station to a station in the earth Deep Space Network. The signal will then be relayed to Mission Control if necessary and then retransmitted to the base. This process will introduce a short (1-2 second) delay in the transmission and receipt of the signal. For this reason it will not be useful in providing accurate location data for the lander, but will be adequate for all other uses.

Since the lander will need to be in constant contact with the station during assent, it will not be launched until the station enters the line of sight of the base. As mentioned before, this is a 26 minute period and since the lander only takes 10-15 minutes to reach orbit, there is plenty of time in the direct communications phase for a safe launch to occur.

2.4 STATION-TO-STATION

The station's modular design allows for great safety in that modules can be lost without causing a loss of the entire station. While this is necessary for such a station, it causes unique problems in the area of communications. The astronauts onboard will need to talk to others in different areas of the station, and controllers on earth or on the moon will want to communicate with astronauts on the station while they are at work in various modules. For these reasons it is necessary to have a means for communicating with all parts of the station.

The method chosen to accomplish this goal is a fiber optic based digital system. Fiber optics was chosen because it is small, lightweight, and has the capacity to carry thousands of signals. It is also good because it is immune to interference caused by solar radiation. As a backup in case of failure, there will be an infrared transmission package on each module. The mechanics of the system will be similar to the system developed for use of the Skylab missions. Each crew member will carry a small receiver transmitter about the size of a portable radio. This receiver will be accompanied by a small microphone, worn either on the chest or around the head. The receiver will pick up voice signal and transmit them to another receiver located in each compartment. The signal will then be coupled with the image data provided by one of the several closed circuit cameras in each module and sent through fiber optic wires to the rest of the station. Every other module will then receive the signal and display the image on a small screen and transmit the voice signal out to any crew members in range where it can be heard in the crew member's earpiece.

The system will also have the ability to localize the signal so it will be broadcast only to a certain module holding the other party in the conversation. The crew members receiver/transmitter will broadcast a code along with the signal that will identify the sender. The sender can request that his message only be sent to a specific crew member, thereby allowing for private conversations. The message can also be sent to the external communications center and transmitted to the base or to earth.

This type of system has many options. First it allows crew members the freedom to communicate from any where in the ship. This is very important in the case of an emergency where the crew member can not move from his location. Secondly, the system also provides a way to locate a crew member since the module he is transmitting form can be identified by the system. Thirdly, by allowing for individual transmissions, the system will let several conversations proceed simultaneously, unlike a conventional intercom system.

As mentioned before there is a backup communications system in the event that the fiber optic cables are severed for any reason. This backup system is an infrared version of the primary system. Internal to the module the system will operate as normal. The module will then send the signal to an external infrared transmitter instead of through the damaged line. This transmitter will then send the signal to receivers on the outside of the rest of the modules where it will then be processed and re transmitted as before. This will allow for communications even if one of the modules becomes completely detached from the station.

SUMMARY OF COMMUNICATIONS

LUNAR STATION

1. ORBIT SPLIT INTO THREE TYPES OF COMMUNICATIONS

   - 26 MINUTES OF DIRECT LINK WITH BASE
   - 64 MINUTES OF EARTH RELAY TO BASE
   - 37 MINUTES OF TOTAL BLACKOUT

2. ADDITIONAL BLACKOUT MAY OCCUR DUE TO ADVERSE WEATHER CONDITIONS OVER THE EARTH RECIEVING STATIONS.

   - ESTIMATED ADDITIONAL BLACKOUT 10-15 MINUTES PER MONTH

3. RELY ON NASA DEVLOPMENTS FOR THE RECIEVING STATIONS ON EARTH. ASSUME THAT SUFFICENT CAPABILITY WILL BE PRESENT.

4. EXTERNAL COMMUNICATIONS:

   - 2 OMNIDIRECTIONAL PARABOLIC ANTENNAS DIAMETER = 1.5 TO 2 METERS.
   - ANTENNAS PLACED ON TRUSS
   - TRANSMISSION BAND - Ku

5. INTERNAL COMMUNICATIONS:

   - FIBER OPTIC LINE TO CARRY VOICE, DATA AND IMAGES BETWEEN MODULES.
   - BACKUP INFRARED TRANSMITTER/RECIEVERS ON THE OUTSIDE OF THE MODULES.

6. STATION TO LANDER:

   - TRANSMISSION ON Ku BAND
   - USE SAME ANTENNA AS EXTERNAL SYSTEM

CHAPTER 9

ECONOMIC CONSIDERATIONS

INTRODUCTION

As the Earth's geosynchronous Space Station is in its final stages of design and implementation, it is only logical that we look ahead to the next milestone in space exploration. It is inevitable that a moon outpost will be our next goal. In an effort to perform a preliminary analysis on the requirements and economic feasibility of such an ambitious project, it will be necessary to illustrate and identify the economic trade-offs involved.

Although it may be a few decades before man can establish a lunar outpost such as the one proposed in this report, the lead time to develop and implement such utilization will also take as long. Thus it is crucial that we consider the economic feasibility and requirements of lunar resource development and utilization.

From previous geological surveys of the lunar surface (as performed during the Apollo program), the soil of the moon is composed of 85 to 90% of the non-fuel yet non-recoverable elements used by the United States and other industrial power-houses. Additionally, when the cost of transporting raw materials into outer space is considered, the fundamental difference in gravitational strengths between the moon and the earth becomes a significant factor. The huge mass of the earth means that a very high escape velocity (11.2 km/sec) is required. When combined with the aerodynamic drag due to the extending regions of the atmosphere, the energy requirement for ejecting an object from earth is approximately 22 times that of the moon. From these basic arguments, the moon is an incredible economic asset and saving for space based manufacturing.

USEABILITY AND MANAGEABILITY OF LUNAR RAW MATERIALS

The major problem facing modern industrial world is to find an alternative to fossil fuel. As proposed by Dr. Criswell and Dr. Waldron of the Lunar and Planetary Institute in their paper on the Commercial Prospects for Extraterrestrial Materials, non-renewable resources to replace the hydrocarbons can be extracted from lunar soil. Let us define an imaginary geological sample which consists of the 16 required elements necessary for U.S. industrial and manufacturing processes. Surprisingly enough, 11 of these 16 can be obtained from lunar soil with less than a factor of 10 in concentration enhancement. The following table illustrates this,

Element	Weight Fraction Req.	FractionAvail.	Enhan. Factor
Oxygen	0.455	0.413	1.10
Silicon	0.244	0.242	1.13
Calcium	0.142	0.070	2.00
Carbon	0.057	0.0001	570.0
Iron	0.048	0.134	0.31
Aluminum	0.0023	0.546	0.042
Magnesium	0.0017	0.0681	0.025
Potassium	0.0021	0.0008	2.6

Phosphorus	0.0019	0.0005	3.8
Nitrogen	0.0083	0.0001	83.0
Sodium	0.0095	0.0023	4.1
Sulfur	0.0058	0.0006	9.7
Hydrogen	0.0025	0.00007	350.0

Thus, from an elemental standpoint, the industrial requirements can be met with the available resources in the lunar soil. Furthermore, the profitability margin can be substantial due to the benefits of zero or low-g manufacturing.

OPTIMIZATION OF PROCESSING AND MANUFACTURING COSTS

The primary problem in space manufacturing is the high cost of transporting materials and supporting structures to and from space. Thus production costs must be low enough to compensate or overshadow the transportation costs. A first step in optimizing production costs would be a survey of the processes which may be free because of space siting. These include:

- no grinding of raw materials is required.
- cheap energy from the sun.
- cheap source of raw materials (no mining necessary).
- lack of gravity.
- cheap vaccuum and therefore contamination free environment.
- cheap means of waste and by-product disposal.

Because of these advantages, numerous industries will find the space manufacturing to be an attractive economic consideration. We envision our list of potential clientele to include companies from the following industries:

- Ceramics manufacturing.
- Fiber optics and glass manufacturing.
- Electrochemical processing.
- Semi-conductor synthetic gem manufacturing.
- Micro-electronics circuit technology.
- Uranium and plutonium recovery processing.

Other production steps which are considerably cheaper in space will be possible in the near future. Such device as the plasma arc, which is now operational, can be utilized in eletro-metallurgy - this technology will not be applicable in large scale smelting processes unless signifiant advances are made in fusion power technology.

The most cost efficient method of obtaining ferrous metals from the lunar surface is by magnetic separation of metallic iron particles from the lunar regolith. Further refinement can then be done using vacuum smelting with hydrogen recovery.

In summary, optimization of local production cost is imperative and crucial to the balancing of net yield versus production costs and overhead capitals. If production costs are not sufficiently low, the concept of space based manufacturing will become an economic impossibility.

QUANTIFYING THE ECONOMIC WORTH OF SPACE MANUFACTURING

When capital requirements, production costs, and the immense array of other factors are taken into consideration, the result of such an interdependent analysis is a mathematical nightmare. For the sake of simplicity, yet retaining a reasonable degree of accuracy, a mathematical model can be developed :

$$X_i + Y_i - \sum_j A_{ij}X_j \geq D_i,$$

where D_i is the annual final demand for the ith product,
X_i is annual quantity of local production,
Y_i is annual quantity of imported material,
and, A_{ij} is the annual quantity of the ith product required as an intermediate step to produce the jth product.

From this model, it is evident that if the demand quantity is greater than the summation of productivity terms on the left side, than the venture of space manufacturing becomes an economic failure.

According to Dr. Robert Ayres of the Carnegie-Mellon University, further simplifications can be made by eliminating lot size and set-up time for short production runs. In his paper, Economic Considerations in Space Industrialization, these factors, although critical to earth-bound production, were proven to be negligible in the inventory of space production costs.

Another simplification can be made in the interrelation of product technologies. The assumption of a unique technology for each product is an avoidable yet fortunate one. By doing so, each product is treated a separate industrial quantity, simplifying the A_{ij} matrix in our equation.

Overall, the quantification of space-based industrialization can simulated by a relatively simple yet accurate model. The criterion for success now is for us to satisfy the inequality.

DISTRIBUTION LIST - "A LUNAR SPACE STATION"

Copy No.	
1 - 3, S/S unbound 4 - 5, D/S bound	NASA/USRA Advanced Design Program 17225 El Camino Real, Suite 450 Houston, TX 77058
6 - 7	J. K. Haviland, MAE
8	M. A. Townsend, MAE
9 - 10	E. H. Pancake, Clark Hall
11	Pre-award Administration Files

JO#2559:jame